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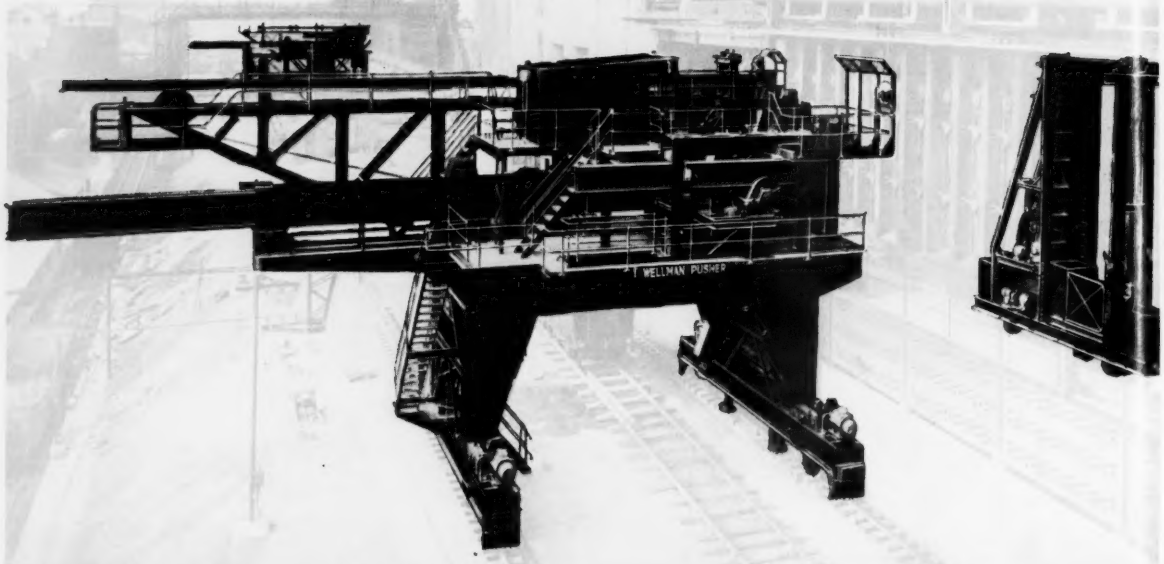
Another Wellman Record



IN 1923 the first Combined Coke Pusher, Coal Leveller and Door Extracting Machine, the result of Wellman Engineering development and skill, was ordered together with Coal Charging Car, Combined Coke Guide and Door Extractor, and Coke Car for service on the Coppee-Wilputte Coke Oven Plant of the Consett Iron Co. Ltd. This marked the introduction of modern Coke Oven Machinery to Great Britain.

Now, 25 years later, The Wellman Corporation has supplied and put into service a complete set of Oven Handling Machines for use on the Woodall-Duckham Becker Coke Oven Plant of the Consett Iron Co. Ltd., forming a large extension of the original installation.

The illustration shows in the foreground the Pusher Machine of portal construction embodying many improved features designed to facilitate operation and reduce maintenance. The original machine on the Wilputte battery can be seen in the background, and is still rendering excellent service.

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PARNELL HOUSE, WILTON ROAD, LONDON, S.W.1 WORKS: DARLASTON, SOUTH STAFFS.

CARL A. F. BENEDICKS, Fil. Dr.

CARL AXEL FREDRICK BENEDICKS, former Director of the Metallografiska Institutet of Stockholm, was born at Stockholm in 1875. He was educated at the Beskowska School and at the University of Upsala, where he was awarded the degrees of Fil. Lic. (1902), Fil. Dr. (1904), Dr. Ing. e.h. (1929), and Dr. Techn. h.c. (1937).

Dr. Benedicks began his career as a university lecturer in 1904. In 1911, he was appointed Professor of Physics at the University of Stockholm and from 1920 to 1935 he served as Director of the Metallografiska Institutet. The results of his scientific activities were not, however, confined to Sweden, and he rapidly acquired an international reputation as a scientific thinker and research worker in ferrous and non-ferrous metallurgy. In 1902 he received the Bergstedt Prize, followed two years later by the Edlund Prize and, in 1908, by the Carnegie Gold Medal. He was awarded the Arnberg Prize in 1919, the Prix Henry Wild in 1922, the Bessemer Gold Medal in 1927, and the Prix Becquerel in 1936. In addition, he has been decorated by Poland, France, and Sweden.

The author of many scientific and technical papers, Dr. Benedicks is particularly well known for the discoveries of the thermo-electric homogeneous effect ("First Benedicks-Effect," 1916) and the electrothermic homogeneous effect ("Second Benedicks-Effect," 1920), which he presented in the Tenth May Lecture of the Institute of Metals, in 1920.

Dr. Benedicks became a member of The Iron and Steel Institute in 1905 and was appointed an Honorary Vice-President in 1922. He is a member of many technical and learned societies, both in Britain and in other European countries. He is a Past-President of the Metals Section of the International Association for Testing Materials.

Carl A. F. Benedicks, Fil. Dr.

Hon. Vice-President

IRON AND STEEL
INSTITUTE PAPERS

PLANT DESIGN · MANUFACTURE · RESEARCH · DEVELOPMENT

High-Frequency Induction Hardening

The Effect of Prior Structure on Carbide Solution under Extremely Rapid Heating Rates

By R. J. Brown, F.I.M., A.M.I.Mech.E.

SYNOPSIS

The effect of extremely rapid heating rates upon the structure of the surface layers of 0·35–0·40% carbon steel and manganese–molybdenum steel of similar carbon content is recorded, and the effect of the prior condition of the steel in relation to carbide solution and homogenization of carbon distribution in the final structure is discussed.

The steels were skin hardened by the high-frequency induction process, with prior structures ranging from the coarse agglomerate condition produced by slow cooling after overheating, to the relatively homogeneous condition produced by hardening and tempering.

Prior dispersion of the carbides was found to affect appreciably the final hardness of the surface layers, this property being dependent upon the degree of dispersion of the carbon atoms in the matrix at the time of quenching. The specimens were skin hardened by the progressive method, the surface reaching the hardening temperature in 0·25 sec.

Introduction

It has already been established that carbide solution during heating for hardening occurs by a process of nucleation, followed by a migration of a proportionate number of the carbon atoms, within the austenite zone, into any surrounding or admixed ferrite as heating proceeds, until a condition of uniform carbon dispersion, or homogenization, is achieved. The rapidity of solution of the carbides, even under normal conditions of salt-bath heating, has been shown by Lauderdale and Harder.[1] The growth of the austenite grains within a steel during heating has been investigated by Baeyertz,[2] and by Digges and Rosenberg,[3] who proved that formation of the austenite grain was influenced by the form of the carbide, austenite formation proceeding along the direction of the lamellae in pearlitic materials, with nucleation occurring at the ferrite–cementite boundaries within the pearlite colonies. They further showed that austenite grains do not readily grow across the ferrite grain boundaries separating the original pearlite colony. With spheroidized steels, transformation and solution first occurs at the ferrite–cementite boundaries surrounding those carbide particles lying on the original austenite grain boundaries, and as the temperature is increased these austenite grainlets grow in size, and solution of the carbides within the residual-ferritic zone progresses preferentially along the ferrite sub-grain boundaries until the continual growth, and austenite formation, involves the whole of each grain, which will then possess reasonable uniformity of carbon dispersion. Roberts and Mehl[4] have confirmed that the rate of austenite nucleation and subsequent growth is dependent upon structure-sensitive properties, and that rate of growth of austenite is related to the carbide–ferrite interfacial area.

The effect of prior structure on heat-treatment response has been studied by Welcherer, Rowland, and Ubben,[5] who state that the size, shape, and distribution of the carbides control the soaking time necessary to achieve optimum hardenability, and that for the normalized condition the advantage of long soaking times has been over-emphasized. According to Martin and Wiley[6] the effect of prior structure upon the behaviour of a plain carbon steel during induction heating is pronounced, a lamellar material necessitating higher temperatures for the attainment of homogeneous austenite as compared with a sorbitic steel. The basic metallurgical principles of induction hardening are no different from those for conventional hardening, but maximum hardness is attained with only about 90% martensite. The

Manuscript received 4th May, 1948.

Mr. Brown is Chief Chemist and Metallurgist at the Nuffield Central Research Laboratories.

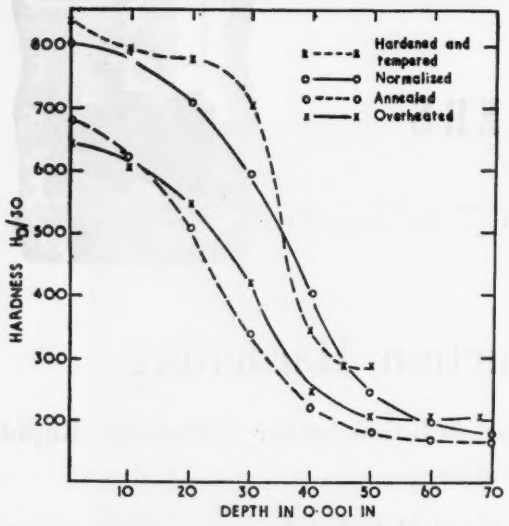


Fig. 1—Hardness gradient through skin of En 8C

mode of solution is stated to be similar to that described by other workers, pearlite transforming to austenite at temperatures between 700 and 750° C, the transformed areas growing by progressive dispersion of the carbon into the surrounding ferrite as the temperature increases. The "minimum" temperature dependent upon the carbide form and distribution is necessary for the attainment of maximum hardness ; beyond this temperature the hardness may fall. The higher hardness of induction-treated steels is considered to be due to carbon-concentration gradients associated with internal stress, and homogeneity of the austenite is likely to result in reduced hardness, together with a reduction in fatigue resistance, due to the consequent reduction in the compressive stresses in the surface of skin-hardened materials. Normalized steels containing over 0·45% of carbon are said to respond satisfactorily to induction-hardening methods, the hardening temperature being given as 850° C. Temperatures greater than 1000°C result in increased depth of the hardened zone and increased homogenization of the austenite, associated with reduced hardness and fatigue resistance. The similarity of the metallurgical characteristics of induction-hardened and furnace-hardened steels is confirmed by Poynter,[7] and the effect of increasing the heating time for a given depth of hardened zone with low-power input, or alternatively, heating to higher surface temperatures at the same power input, is recorded. The possibility of minimum hardness in the transition zone is noted, and the probability of the effect of frequency upon depth of hardening having been over-emphasized, as compared with the effect of heat conductivity from the surface layers, is remarked upon.

The metallurgical functions involved in induction heating have also been investigated by Martin and Van Note,[8] and they suggest that steels with a low A_{c1}–A_{c3} temperature, and little free ferrite, with medium to deep hardenability, are the most suitable for this method of hardening. The effect of alloying elements is discussed in view of their influence in reducing the A_{c1}–A_{c3} temperature, together with their effect on the distribution of the carbides. Alloy steels austenitize in the furnace-cooled condition more readily than carbon steel.

The conclusions enumerated above relating to induction-hardened materials were based upon samples heated by single-shot methods, whereas a considerable proportion of skin-hardening can be, and is being, successfully achieved by the progressive method, which, owing to continuity of the process, is more economical.

The object of the present research was to establish the effect of extremely short heating rates upon the surface structure of hypo-eutectoid steels, skin hardened by the progressive method.

EXPERIMENTAL PROCEDURE

Two steels were employed in this investigation, a plain carbon steel and a manganese–molybdenum steel, conforming to the requirements of En 8C and En 16C respectively. The compositions of the actual samples employed are given below :

	En 8C, 0·40% Carbon	En 16C, Manganese–Molybdenum
Carbon	0·38%	0·37%
Silicon	0·19%	0·20%
Manganese	0·75%	1·47%
Sulphur	0·027%	0·034%
Phosphorus	0·076%	0·037%
Nickel	0·03%	0·15%
Chromium	0·07%	0·10%
Molybdenum	Nil	0·32%

These were surface hardened in the form of $\frac{1}{2}$-in. dia test bars machined from hot-rolled bar stock of $\frac{3}{4}$-in. dia after subjection to the following treatments :

Condition Required	Steel	Heat-Treatment
Overheated	En 8C	1 hr at 1250° C, furnace-cooled
Overheated	En 16C	1 hr at 1250° C, furnace-cooled
Annealed	En 8C	1½ hr at 860° C, furnace-cooled
Annealed	En 16C	2 hr at 860° C, furnace-cooled
Normalized	En 8C	1½ hr at 860° C, air-cooled
Normalized	En 16C	2 hr at 860° C, air-cooled
Sorbitized	En 8C	1¼ hr at 860° C, oil-quenched, and tempered for 2½ hr at 650° C, air-cooled
Sorbitized	En 16C	1¼ hr at 860° C, oil-quenched, and tempered for 2½ hr at 650° C, air-cooled

The resulting microstructures of these steels, in the four conditions, are referred to in a later section of this paper, the treatment having successfully achieved the desired range of grain-size and carbide formation likely to be encountered in steels of minimum carbon concentration, suitable for skin hardening by the H.F. induction process.

Surface hardening of the test specimens was carried out by the progressive method at a rate of $\frac{3}{4}$ in/sec, using a single-turn inductor $\frac{3}{16}$ in wide, having a radial clearance of $\frac{1}{16}$ in, fed from a generator of the electronic type, operating at a frequency of 400 Kc., with a maximum output of 20 kW. The actual heating time to achieve the full hardening temperature was 0·25 seconds for any portion of the surface of the

samples. An H.F. transformer having an 18/1 ratio was interposed between the generator and the inductor, the secondary winding consisting of water-cooled sheet copper surrounding the primary winding of $\frac{1}{4}$-in square copper tubing as illustrated in Fig. 3, which also shows the inductor and the feed plates connecting it to the transformer. The method of feeding the H.F. current to a single-turn inductor is of extreme importance owing to the impedance offered to the flow of the current at the edges of the gap in the conventional form of this type of inductor.

The specimens were processed on the handling machine shown in Fig. 4, being held vertically between centres. The work table is provided with the means for effecting controlled variation in the traverse speed within wide limits.

The power consumed by the generator during heat-treatment of the specimens was 30 kW, at 400 V, and the power delivered to the work was 6·9 kW showing an overall efficiency of 23%, this figure including all incidental losses. This efficiency is low, and under optimum conditions could be increased to 40% with the particular generator employed. The H.F. load on the generator was 140 kVA at a power factor of approximately 0·048; the area of bar surface disposed in the immediate field of the inductor was 0·29 sq.in., the mean power density being 23·8 kW/sq.in.

Quenching of the specimens was by means of water sprayed through a quench ring located immediately beneath the inductor, the bar specimen being progressed in the downwards direction. The distance between inductor and quench is of major importance, being in the present series of experiments $\frac{1}{4}$ in, and it is essential that the volume and pressure of quenchant at all points within the quench ring is uniform, that the pressure is sufficient to prevent the formation of gas pockets in the quenching zone, and that the quenchant forms an actual jacket around the bar to within a short distance of the inductor. The temperature to which the samples were heated as they passed through the inductor was approximately 850° C for all conditions as measured with an optical pyrometer.

EFFECT OF PRIOR CONDITION

The effect of prior condition of the steel upon microstructure and hardness of the heated and quenched skin under the standard conditions of processing, described in the preceding section, was determined by making a hardness traverse through the surface layers by their progressive removal, and by preparing longitudinal sections of the processed bars for micro-examination.

Hardness

The hardness gradients through the surface layers of the various samples are shown in Figs. 1 and 2, from which it will be seen that maximum hardness is attained in the sorbitic materials, with the hardness falling only slightly through the hardened zone. The normalized material developed slightly lower peak hardness, but the gradient changes more rapidly through the hardened layer. There is little effective difference between the annealed and overheated

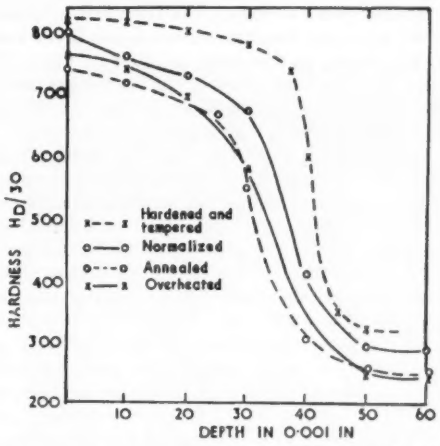


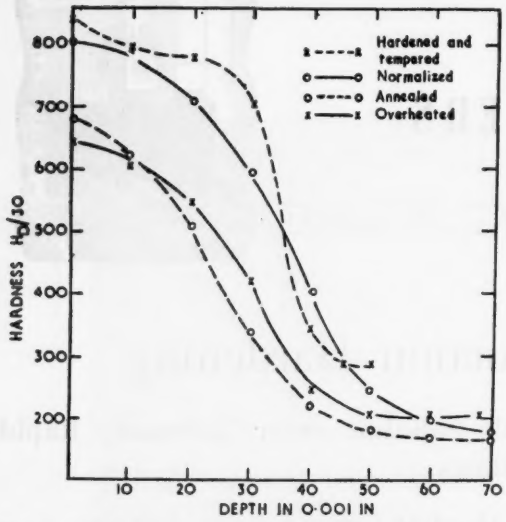
Fig. 2—Hardness gradient through skin of En 16C

materials, and the gap between the hardness gradient for these and the normalized condition is only slight for the alloy steel, but marked for the carbon steel, this being due to the greater dispersion of the carbides and proportionately less massive ferrite in the alloy steel. There is no evidence whatever of a soft and therefore weak zone between the hard surface layer and the core, referred to by Almen[9] and by Poynter.[7] This is considered to be due to the extremely rapid heating and quenching rates employed, which removes any possibility of a tempered zone as the result of heat conductivity from the heated layer into the cold core.

Microstructure

The initial structures of the test specimens are illustrated in Figs. 5–8 for the carbon steel, and Figs. 9–12 for the alloy steel. Both series show progressive refinement of the grain size and reduction in width of the ferrite network from the overheated to the normalized condition, and uniform carbide dispersion in the sorbitic condition. Comparison of the slowly cooled carbon and alloy steels shows considerably greater dispersion of the carbides in the latter, together with a proportionate reduction in the amount of massive ferrite, this accounting for the greater similarity of the hardness gradients for the overheated, annealed, and normalized conditions of the alloy steel.

The structures of the entire hardened surface layers are illustrated in Figs. 13–16 for the carbon steel, and Figs. 17–20 for the alloy steel. The effect of the relative proportions of free ferrite upon the solution rate is clearly demonstrated, particularly in the case of the carbon steel, undissolved ferrite being visible throughout the hardened zone in both the overheated and annealed samples, and throughout the major portion of the heated zone for the normalized condition. The persistence of ferrite in the immediate surface layers of the overheated and annealed samples is shown in Figs. 29, 30, 33, and 34, and the similarity between the normalized and sorbitized samples in Figs. 31, 32, 35, and 36.



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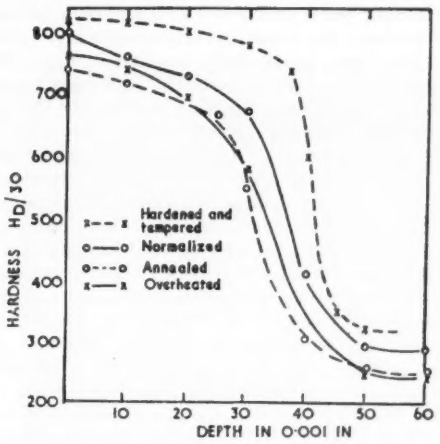

Fig. 2—Hardness gradient through skin of En 16C

materials, and the gap between the hardness gradient for these and the normalized condition is only slight for the alloy steel, but marked for the carbon steel, this being due to the greater dispersion of the carbides and proportionately less massive ferrite in the alloy steel. There is no evidence whatever of a soft and therefore weak zone between the hard surface layer and the core, referred to by Almen[9] and by Poynter.[7] This is considered to be due to the extremely rapid heating and quenching rates employed, which removes any possibility of a tempered zone as the result of heat conductivity from the heated layer into the cold core.

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A further point of interest is the narrow transition zone between the hardened martensitic layer and the core, this being particularly marked in Figs. 13, 16, 19, and 20. The structures of the transition zones are shown at higher magnification in Figs. 21–24 for the carbon steel, and Figs. 25–28 for the alloy steel. The overheated carbon steel (*see* Fig. 21) shows an abrupt change from a martensitic condition of the eutectoid grains to a pearlitic condition, and this abrupt change has in actual fact cut across those eutectoid grains lying along the line of transition. The same abrupt change is also observed in the annealed sample (*see* Fig. 22), but in the normalized material the change is less abrupt (*see* Fig. 23). This is due to the smaller size and greater dispersion of the eutectoid grains which permit a more progressive state of solution of the carbides in the ferrite, from the bottom to the top of the heated zone. Even the sorbitized sample has a relatively abrupt change in the transition zone (*see* Fig. 24) from martensite to sorbite, this zone constituting an agglomerate of small spheroid-like particles of ferrite in martensite, the proportion of ferrite decreasing rapidly in the direction of the surface.

The transition zones in the alloy steel are much more gradual, due to the greater dispersion of the carbides even in the overheated sample (*see* Fig. 25), although the change from pearlite to martensite is quite sudden where the grains containing carbides are well defined and are of nominal eutectoid composition (*see* Fig. 26). The spheroidal form of the dispersed ferrite in the transition zone is shown both by the normalized sample in Fig. 27, and by the sorbitic sample in Fig. 28.

It might be assumed that the observed separation of ferrite in the transition zone between the hardened skin and the core would be associated with minimum hardness in the sorbitic samples, but the absence of such a soft zone is undoubtedly due to the matrix being either of martensite, or of an intermediate product which has a greater hardness than the original sorbite.

DISCUSSION ON MODE OF SOLUTION

In order to determine the relative modes of carbide solution in steels which have prior structures of ferrite–pearlite agglomerate or sorbite, the 0·40% carbon specimens, annealed and sorbitized, were examined at relatively high magnifications ; typical areas from the core to the surface of the hardened zone are shown in Figs. 37–40 for the annealed sample, and Figs. 41–44 for the sorbitized sample, from which it will be seen that the mode of solution is somewhat different.

A comparison of the equivalent structures of the various zones is of importance, indicating, as it does, a marked difference in the manner whereby the carbides are initially taken into solution and become subsequently dispersed in order to form homogeneous austenite. The initial structures of the annealed and normalized samples in Figs. 37 and 41, show the former to consist of well-defined grains of lamellar pearlite in a coarse matrix of ferrite, and the latter to consist of a uniform dispersion of extremely fine carbide particles in a ferritic matrix, the structures of both being typical of the conditions represented.

The structures at the base of the heated zone (this being the circumferential band heated to the lower part of the A_{c1}–A_{c3} temperature band for the minimum of time) indicate marked dissimilarity (*see* Figs. 38 and 42). In both samples complete carbide solution occurs and results in an agglomerate structure of martensite and ferrite on quenching ; but in the annealed sample, solution occurs within the original pearlite grains, whereas in the sorbitic sample, solution occurs at numerous points throughout the steel, with the formation, on quenching, of pools of ferrite in a matrix of martensite, which is assumed to be of eutectoid composition. Homogeneity of solution after the A_{c3} temperature has been attained is a function of time and of structure, this being shown by Figs. 39 and 43, representing the conditions existing midway between the surface of the specimens and the base of the heated zone, whereas the sorbitic sample has reached an apparently uniform condition of carbide solution. The annealed sample contains considerable free ferrite owing to the distance over which the carbon atoms must migrate into the gamma iron during heating before uniform solution is achieved. The progressive migration of the carbon into the gamma iron is clearly shown in the micrographs of the annealed steel, the outline of the transformed pearlite grains first becoming slightly ragged as the carbon is absorbed from their surface into the surrounding iron (*see* Fig. 38). As migration proceeds with increasing temperature, the outline of the transformed grains becomes less clearly defined, a carbide solution gradient between the ferrite and martensite areas being evident (*see* Fig. 39) ; even in the surface layers carbon migration is not complete, although the carbon atoms appear to have completely bridged the initial ferrite areas, with the formation on quenching of areas of martensite with varying carbide concentrations. A significant feature of the ferrite areas in the hardened skin of the slowly cooled steel is the recrystallization which has occurred, the grain size becoming progressively smaller from the transition zone to the surface of the samples. It is suggested that this effect is associated with a condition of intense stress set up on transformation of the surrounding austenite to martensite, the stress being dependent upon the ratio of austenite to iron, and also upon the normal contraction effects produced by the severe quench.

CONCLUSIONS

(1) A sorbitic structure is desirable for those induction-hardening operations such as skin hardening, which involve extremely rapid heating rates ; such a prior condition permits the attainment of a uniform austenite solution in the minimum of time.

(2) It is suggested that, when heated above the A_{c3} temperature, solution occurs within the sorbitic structure by the initial formation of a continuous network of austenitic solid solution surrounding extremely small carbon-free areas of gamma iron, subsequent homogenization being produced by migration of carbon atoms into the carbon-free areas. In

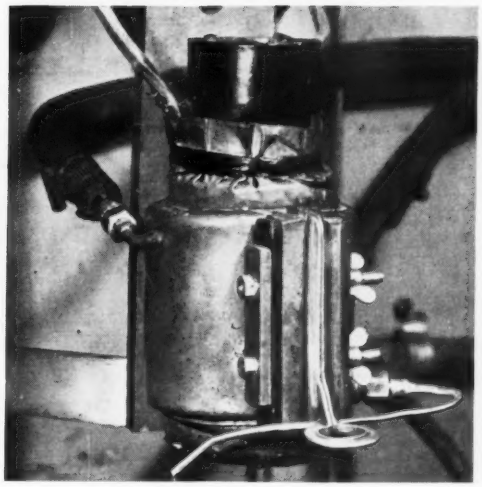


Fig. 3—H.F. transformer with external secondary and single-turn inductor

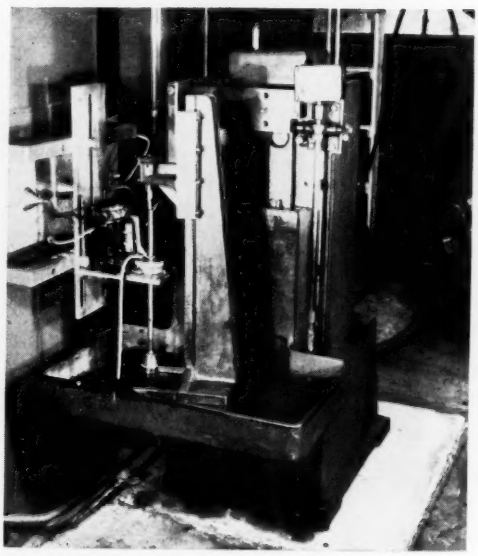
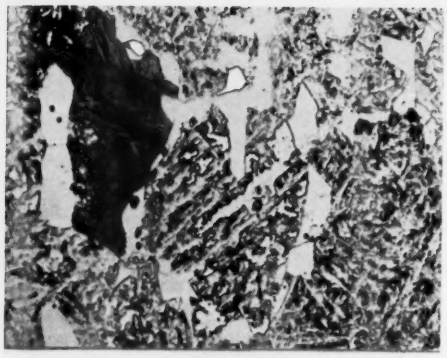


Fig. 4—Handling machine for experimental progressive hardening

Fig. 5

Overheated

Fig. 9



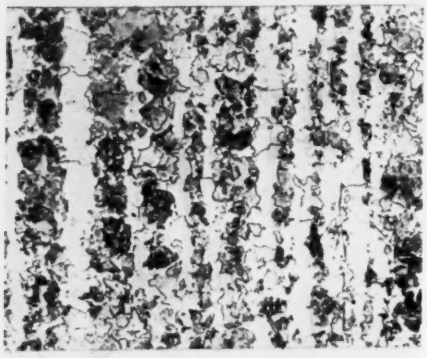
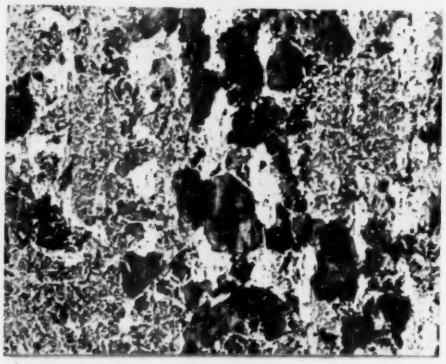


Fig. 6

Annealed

Fig. 10



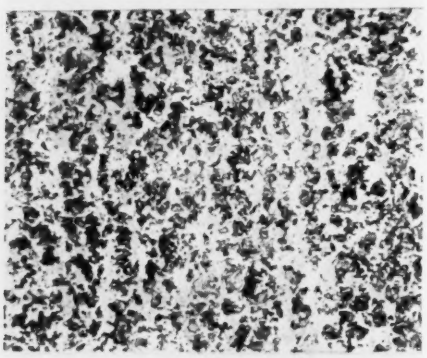
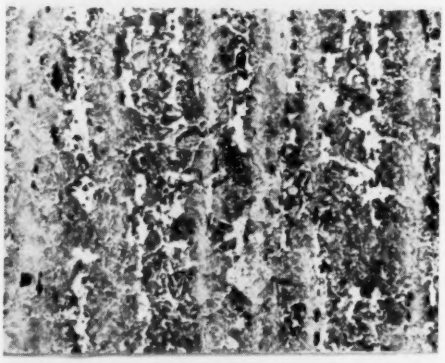


Fig. 7

Normalized

Fig. 11



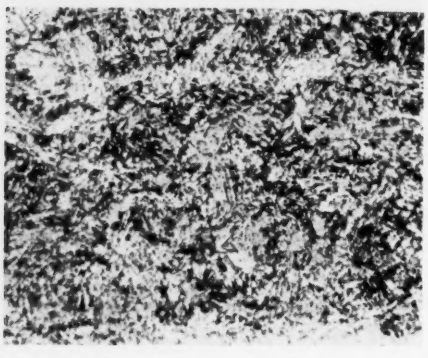
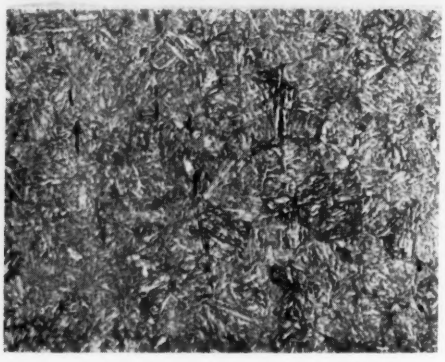


Fig. 8

Hardened and tempered

Fig. 12



Figs. 5 to 8—Microstructures of 0·40% carbon steel (En 8C) × 200

Figs. 9 to 12—Microstructures of manganese-molybdenum steel (En 16C) × 200

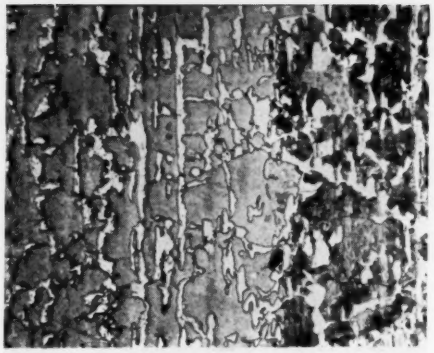


Fig. 13

Overheated

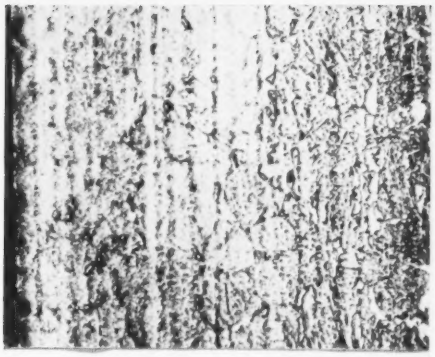


Fig. 17

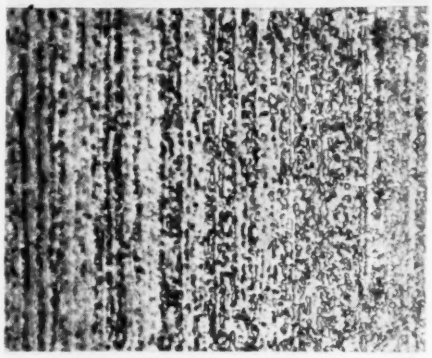


Fig. 14

Annealed

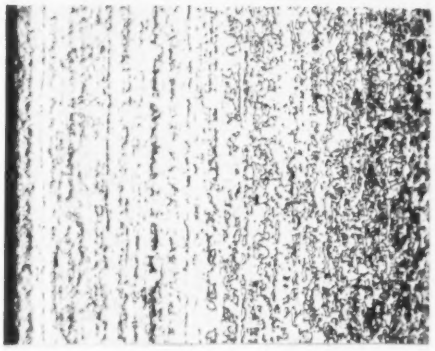


Fig. 18

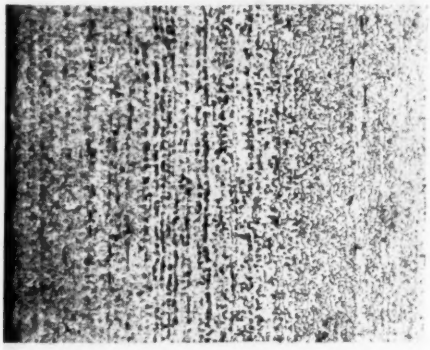


Fig. 15

Normalized

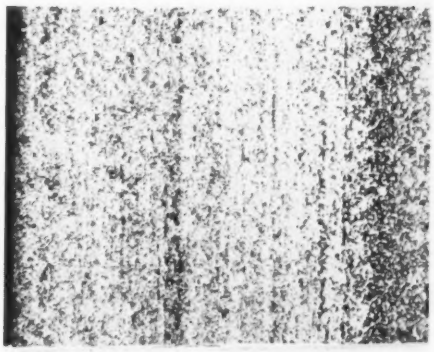


Fig. 19

Fig. 16

Hardened and tempered

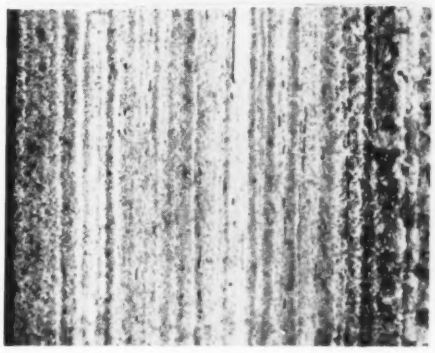


Fig. 20

Figs. 13 to 16—Microstructures of 0·40% carbon steel (En 8C) × 50

Figs. 17 to 20—Microstructures of manganese-molybdenum steel (En 16C) × 50

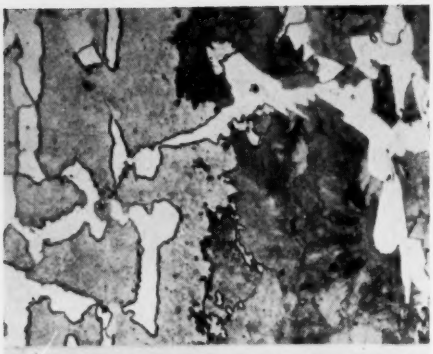


Fig. 21

Overheated

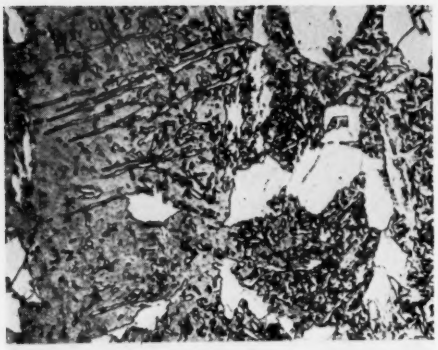


Fig. 25

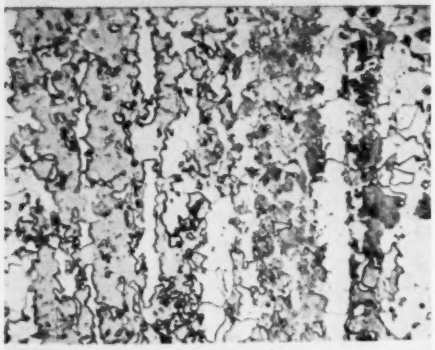


Fig. 22

Annealed

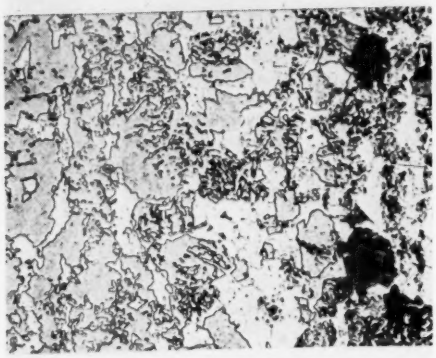


Fig. 26

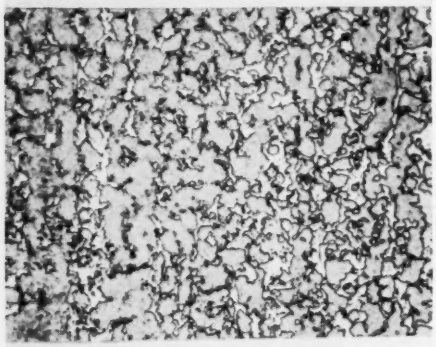


Fig. 23

Normalized

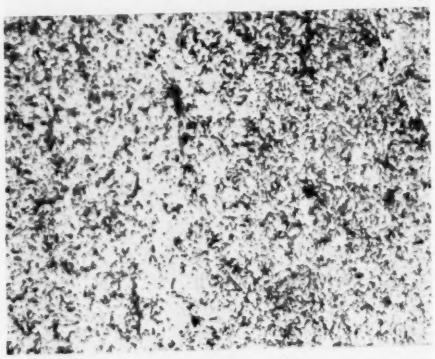


Fig. 27

Fig. 24

Hardened and tempered

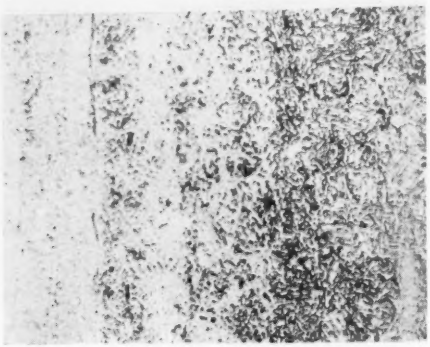


Fig. 28

Figs. 21 to 24—Microstructures of 0·40% carbon steel (En 8C) × 200
Figs. 25 to 28—Microstructures of manganese-molybdenum steel (En 16C) × 200

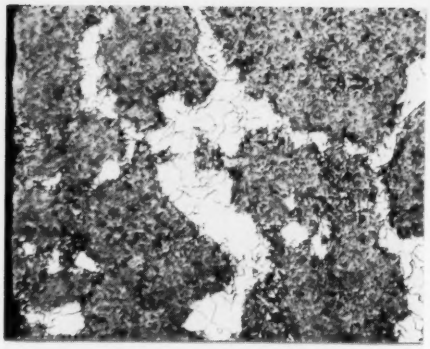
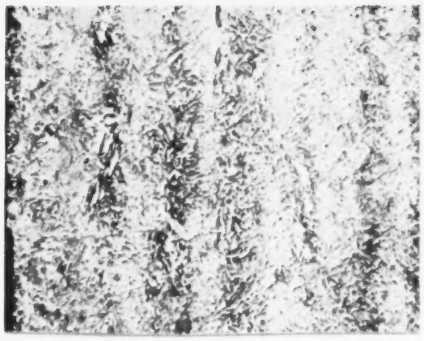


Fig. 29

Overheated

Fig. 33



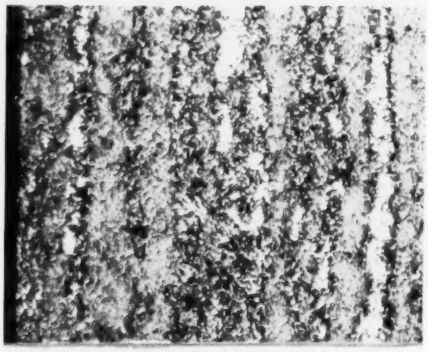
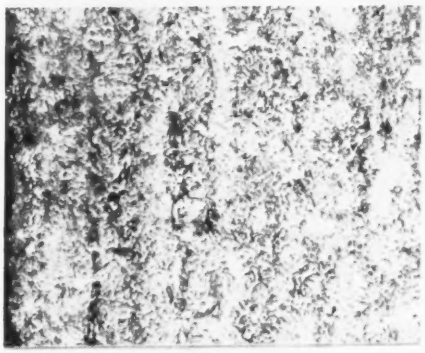


Fig. 30

Annealed

Fig. 34



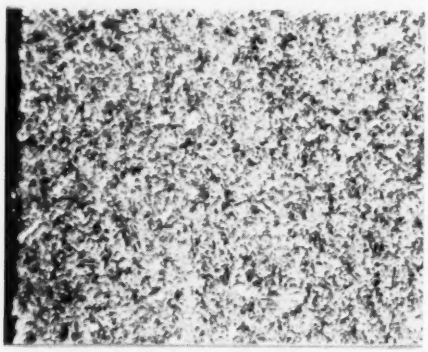
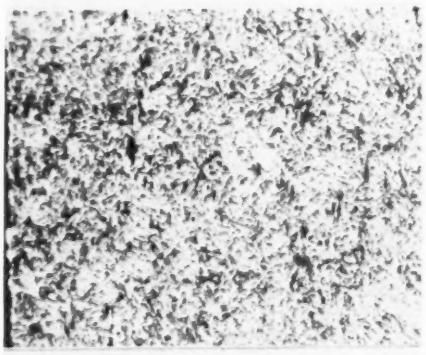


Fig. 31

Normalized

Fig. 35



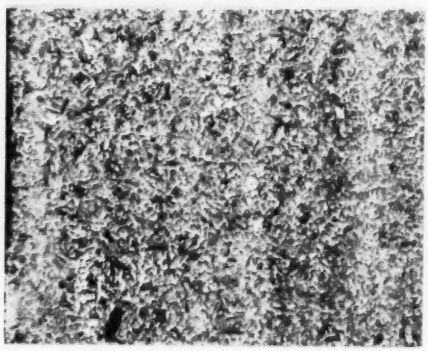
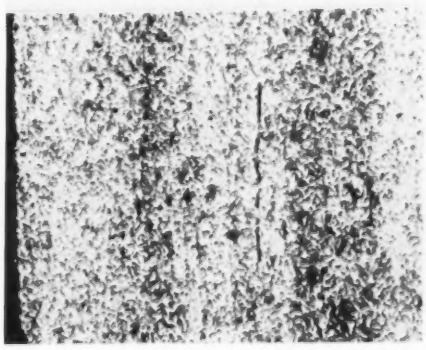


Fig. 32

Hardened and tempered

Fig. 36



Figs. 29 to 32—Microstructures of 0·40% carbon steel (En 8C) × 200

Figs. 33 to 36—Microstructures of manganese–molybdenum steel (En 16C) × 200

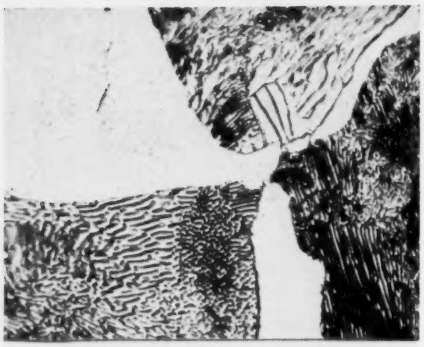
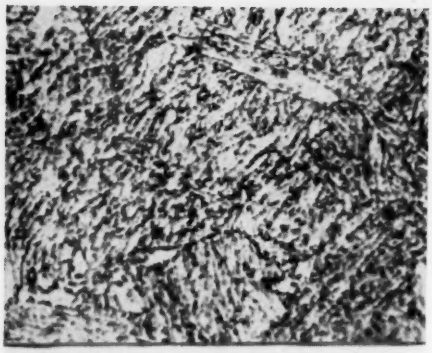


Fig. 37

Core

Fig. 41



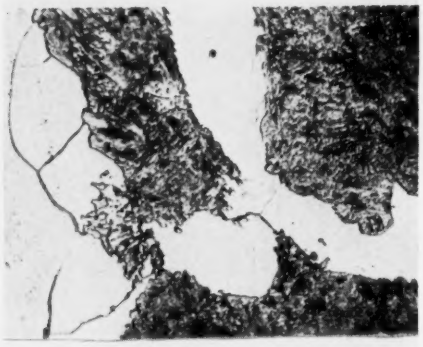


Fig. 38

Base of heated layer

Fig. 42

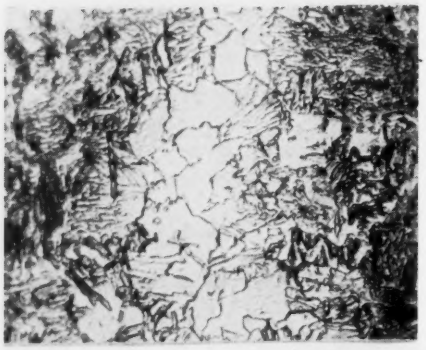
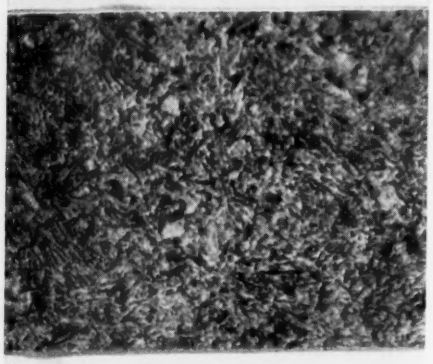


Fig. 39

Midway between surface and transition zone

Fig. 43



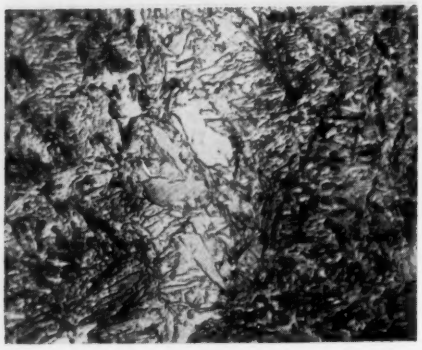


Fig. 40

Immediately beneath surface

Fig. 44

Figs. 37 to 40—Microstructures of 0·40% carbon steel (En 8C) (prior condition—annealed) × 1500

Figs. 41 to 44—Microstructures of 0·40% carbon steel (En 8C) (prior condition—hardened and tempered) × 1500

the pearlitic condition solution occurs initially within the pearlitic grains, the carbon atoms subsequently migrating into the network of carbon-free gamma iron. The relative distance over which the carbon atoms have to migrate controls the speed at which homogenous solution is achieved.

(3) A medium-carbon steel is more sensitive to prior structure than a manganese–molybdenum steel of similar carbon content, owing to the greater initial dispersion of the carbides which occur in the alloy steel under similar conditions of prior treatment.

(4) Carbide solution is essentially a function of temperature, whereas the attainment of a uniform austenite solution in a hypo-eutectoid steel is a function of both time and temperature, the time required for solution above the A_{c3} temperature being related to prior structure under conditions of rapid heating. The essential difference between heating by H.F. induction methods and by conventional furnace methods is that, in the former, carbide solution and austenite homogenization occur in two separate and distinct stages, whereas with normal rates of slow heating, solution and homogenization occur progressively, a uniform carbon dispersion being achieved by the time the A_{c3} temperature is reached.

(5) There is no evidence of a zone of low strength immediately below the martensitic surface layer.

Acknowledgments

The author's thanks are due to Mr. J. Bridle, Mr. J. Powell, and Mr. L. W. Harris, of the Nuffield Central Research Laboratories, whose assistance has made this paper possible; also to the Directors of Morris Motors, Ltd., for permission for its publication.

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HISTORICAL NOTE NO. 8

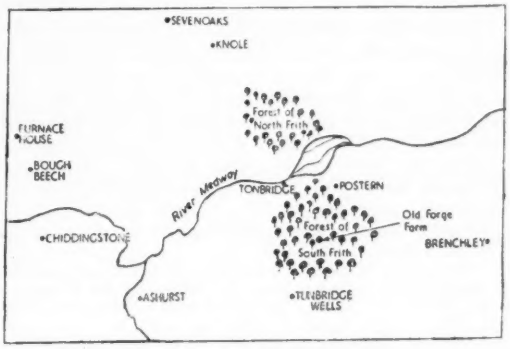
The Northern Extension of the Wealden Iron Industry

By Dr. H. R. Schubert

THE furnace at Bough Beech in the parish of Hever, Kent, is considered by Straker to be "the most northerly of the Wealden furnaces, Ewood (in Sussex), the only other on the northern Weald Clay belt, being slightly more to the south."[1]

The only evidence of this furnace available to Straker was Andrew's map of 1769. New information of a date much earlier is supplied by a deed dated 10th September, 1589, and preserved at Sevenoaks, in Kent.[2] By this deed Thomas Willoughby sold to Thomas Browne, forgemaster of Chiddingstone, in Kent, for the sum of £1074, one hundred and sixty acres of arable land, pasture, and woodground in the parishes of Chiddingstone and Hever, and, in addition, seven acres of meadows in Cransted, in the parish of Chiddingstone, and, further, twenty-two acres of land "together with all manner of furnaces, howses, buildings, and waters, ponds, bayes, woods, underwoods . . . abutting to the highway leading from Bewbeeche (*i.e.*, Bough Beech) to Cransted howse." According to a document of 1629 this land was "known by the common and general name of the furnace farm late,"[2] indicating that the furnace was not worked any longer at that date. Reminiscent of the former furnace is the present Furnace House, north-west of Bough Beech.

Thomas Browne was the first member of a family of English gunfounders who played an important part in the casting of iron ordnance. When he first started work at Bough Beech he was about thirty



The District of Bough Beech

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[1] E. Straker, "Wealden Iron," p. 218. London, 1931 : Bell and Sons, Ltd.
[2] Sevenoaks Public Library, *H*414.

John Dudley, Duke of Northumberland

years of age ; in 1609, when he was about fifty, he had a gunfoundry at Ashurst, in Kent, and deposed on oath that he had " made and sold 463 t. 5¾ cwt. in pieces of iron ordnance " since 1591.[3]

On 30th April, 1604, Thomas Browne took over the furnace at Brenchley, in Kent, from John Iden and Richard Pothill, who had worked it for Sir Thomas Waller since about 1596.[4] At Brenchley furnace Browne evidently started gunfounding on a scale considerably larger than at Ashurst. From 1604 to 1609 he " made and sold " 898 tons 6¾ cwt. of cast-iron ordnance, *i.e.*, an average production and sale of about 175 tons per annum. Like many other contemporary gunfounders, Thomas Browne succumbed to the temptation of selling ordnance abroad, thus contravening the restrictions imposed in order to maintain sufficient supplies for the demands of the Navy and Army. In 1612 three justices of the peace were ordered to seize all the iron ordnance stored at the furnace of Brenchley belonging to Thomas Browne " who has transported much iron ordnance from that furnace against the law restricting the export of such."[5]

In history, the memory of Thomas Browne has been eclipsed by that of his son, John Browne, of Brenchley, who was granted the monopoly of making guns for the Navy in 1614, and the office of the King's gunstone maker, in 1615.[6] Actually, Thomas, the father, was the one who laid the foundations of the manufacture of cast-iron guns, by which his descendants maintained a prominent position in the iron trade throughout the seventeenth century.

The document of 1589, preserved in the Sevenoaks Public Library, supplies new evidence of the place where this family of eminent gunfounders first started work.

Much farther to the north than Bough Beech was an ironworks belonging to the Manor of Knole, near Sevenoaks. The first mention of these works is dated 8th February, 1553, when John Dudley, Duke of Northumberland, reverted the iron mill of the Manor of Knole (" *molendini ferrarii manerii* ") to King Edward VI.[7]

John Dudley is well known in history for his attempt to make his daughter-in-law, the unfortunate Lady Jane Grey, Queen of England after the death of Edward VI. This attempt totally failed and the Duke was subsequently executed on Tower Hill on 22nd August, 1553. John Dudley was " a consummate soldier, a keen politician, and a skilful administrator," but " his character was spoiled by avarice, dissimulation, and personal ambition."[8]

A man of great administrative ability combined with an avaricious mind, such as Dudley, would immediately realize the tremendously lucrative prospects opened to him when Edward VI granted him various castles, manors, and forests extending from Sevenoaks to Tunbridge Wells, making him the biggest landowner in this district. For the utilization of the large forests included in the grant, there was no better way in the sixteenth century than using the supply of wood for the manufacture of iron. Consequently Dudley erected an " iron fornes " in the Forest of Southfrith between Tunbridge Wells and Tonbridge, and a " hammer mill " with fineries in the park of " le Posterne " (*i.e.*, Postern, east of Tonbridge).[9]

It may be suggested that the ironworks of the Manor of Knole, near Sevenoaks, was erected also by John Dudley, Duke of Northumberland, during the two years preceding his execution in August 1553, when he owned the extensive and well-wooded area between Sevenoaks and Tunbridge Wells conveyed upon him in 1551.

The " iron mill " of the Manor of Knole is the most northerly of the ironworks in the Weald of Surrey, Sussex, and Kent.

[3] Public Record Office, Exchequer Special Commissions 7, James I, No. 4143.

[4] *Ibid.*, this is the earliest date of a furnace existing at Brenchley. Straker (*loc. cit.*) refers to the furnace as being worked in 1613 : Victoria County History of Kent, vol. III, p. 386, London 1932, as in 1619.

[5] British Museum, Add. MS. 34218, fol. 16b.

[6] Straker, *loc. cit.*, p. 162.

[7] Calendar of the Patent Rolls, Edward VI, vol. V, p. 179, London, 1926.—This ironworks is not mentioned by Straker, nor by Ch. J. Phillips, " History of the Sackville Family " (who later owned Knole), London, 1930, nor in the Victoria County History of Kent.

[8] Dictionary of National Biography, vol. XVI, p. 110, London, 1888.

[9] Calendar of the Patent Rolls, Philip and Mary, vol. I, p. 286, London, 1937 ; in this document of 1553, November 24, the ironworks mentioned are designated as " newly erected . . . by John, late Duke of Northumberland."—The works at Postern were not known before the above Calendar was published ; Straker (p. 222) refers to " masses of forge cinder under the turf " at a place called Rats Castle which is quite near there. The furnace in the Forest of Southfrith was at " a place called Old Forge Farm from its being in Queen Elizabeth's time an iron foundry " (E. Hasted, History of Kent, vol. V, p. 197, Canterbury, 1798).

High-Speed Rotor Tests of Paints for Under-Water Service

By F. Wormwell, M.Sc., Ph.D., T. J. Nurse and H. C. K. Ison

SYNOPSIS

Part I describes apparatus developed at Chemical Research Laboratory for investigating the corrosion of metals exposed to water or aqueous solutions under conditions of rapid movement (comparable with ships' speeds). An ebonite holder carrying suitably prepared metal specimens is rotated at a controlled speed, the nature and amount of corrosion after varying periods of test being estimated by measurements of weight-loss and depth of corrosion penetration, supplemented by visual examination. The apparatus lends itself to modifications for testing specimens of different forms, for example, rings cut from tubing or portions of wire cable.

Part II deals with the use of the rotor apparatus in testing a series of typical ships'-bottom compositions. These were applied as three-coat systems to the small rotor specimens by use of a special jig, the amount of paint being controlled and measured. Tests were conducted in artificial sea water (similar in composition and *p*H to natural sea water) at speeds of the order of 20 knots for periods up to 50 days. The condition of the paint on each specimen was appraised visually each day ; finally weight-loss measurements were made on selected 50-day specimens. The final qualitative and quantitative results showed good correlation with those obtained in raft tests of the same compositions carried out by Dr. J. C. Hudson. The compositions' order of merit in respect of protection against corrosion was very similar in the two series of tests, but the rotor tests gave results in much shorter periods. It was concluded that the rotor test affords a rapid and convenient method of assessing the value of paint systems intended for use on submerged metals.

Parts III and IV describe the use of the apparatus in comparing the merits of several paints formulated by Fancutt and Hudson. Although the order of merit was not identical in all respects, in the laboratory and raft tests, paint No. 32 (pigmented with white lead, basic lead sulphate, and Burntisland red in a modified phenol-formaldehyde resin–oil medium) showed outstanding superiority in both series. The influence of modifications in the medium of paint No. 173 (based on No. 32) was studied in a further series of tests : some differences were observed, although all the paints showed good adhesion.

Experimental results are given in Part V, showing the acceleration of paint failure and of corrosion of the underlying steel caused by an increase in rate of movement, or by a rise in temperature of the artificial sea water. Part VI deals with methods of assessment of paint failure in rotor tests. Measurements of depth of penetration of corrosion are given for selected paint systems and the results are discussed in relation to the estimates of " useful life " of a paint based on the test-period required to produce loss of adhesion over 10 per cent of the specimen area. The mechanism of blistering, and of paint failure generally, is discussed in relation to the results obtained from tests in sea water and (for a few paints) in fresh waters.

The results as a whole indicate that many paints are now available which adhere so well, even in conditions of rapid movement, that more intensive test conditions are required to evaluate the paints in reasonably short periods. A combination of more intensive conditions of test with more sensitive (electrochemical) methods for detecting paint failure should lead to further advances.

Introduction

THE influence of movement on the corrosion rate of mild steel in salt solutions and natural waters has been studied over a period of years in the Corrosion Section of Chemical Research Laboratory, the investigations having been initiated by the late Dr. G. D. Bengough, F.R.S., and continued under Dr. W. H. J. Vernon, O.B.E. An account of one part of this work, that relating to speeds of movement below 100 feet per min. (" low-speed rotor " technique) has recently been published.[1] A description is now given of the " high-speed rotor " apparatus[2] (originally developed for examining the influence of high rates of movement, *per se*, such as occur on the surface of a ship's hull) with particular reference to its application in the accelerated testing of under-water paints.

The rotor apparatus in its present form was first used in the autumn of 1939 for measurements of corrosion rates of mild steel in 0·5 *N* sodium chloride and in sea water. Preliminary experiments only, on this long-range fundamental investigation had been possible, when an urgent need arose for accelerated tests of ships'-bottom compositions. At the request of the Marine Corrosion Sub-Committee (Joint Corrosion Committee of The Iron and Steel Institute and the British Iron and Steel Federation) the rotor apparatus was adapted for use in testing ships' compositions.

Part I of this paper describes the rotor apparatus ; Part II gives an account of its use in testing a series of proprietary ships' compositions ; Parts III and IV refer to tests of anti-corrosive compositions formulated by Fancutt and Hudson ;[3] Part V deals with methods for accelerating the deterioration of paint coatings ; and Part VI with the assessment of paint failure in rotor tests.

PART I—DESCRIPTION OF APPARATUS

Figure 1 (*a*) gives front and side views of the complete rotor apparatus ; Figs. 1 (*b*) and 1 (*c*) show details

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Dr. Wormwell is a Principal Scientific Officer, Mr. Nurse, a Senior Experimental Officer, and Mr. Ison an Experimental Officer of the Chemical Research Laboratory of the Department of Scientific and Industrial Research.

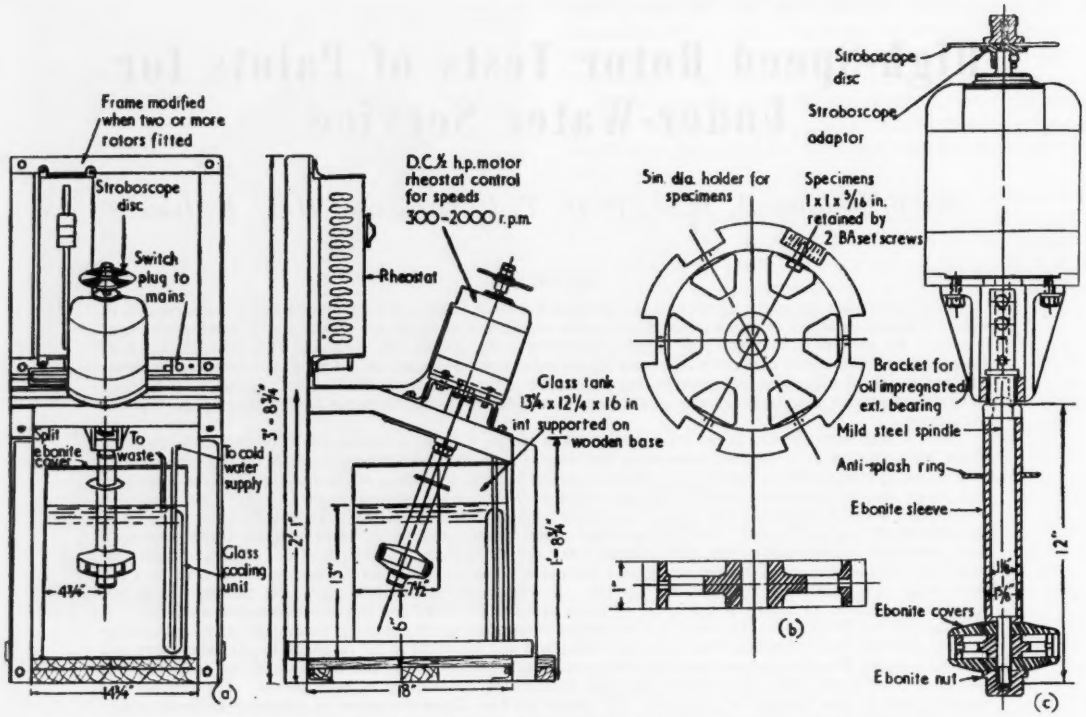


Fig. 1—C.R.L. High-Speed Rotor Unit, showing (*a*) front and side views of whole apparatus, (*b*) section through holder, and (*c*) Motor and Rotor Spindle Assembly

of the specimen holder, the spindle and extension bearing, whilst Fig. 4 shows a battery of six rotor units. Each corrosion specimen takes the form of a plate, 1 in. square and $\frac{5}{16}$ in. thick, which is held in position by a 2 B.A. set-screw, as hown in Fig. 1 (*b*). The surface of the specimen forms virtually part of the outer surface of the 5-in. dia. circular ebonite holder, which moves through the corroding medium at a known speed. In preliminary tests with uncoated mild steel the surface of the metal was turned in a steel "former" (identical in size with the ebonite holder), so that the surface of the specimen followed accurately the curvature of the ebonite. It was found, however, that corrosion results were of a similar order if the specimen was flat; this shape was therefore adopted since, besides being much more convenient to use, it permits the testing of ships' plate without necessarily removing the weathered or pickled surface.

The ebonite holder, carrying six specimens, is mounted between ebonite cover-plates and is attached to the end of an ebonite-covered steel spindle, which is supported in a self-lubricated bearing. The holder is rotated about an axis inclined at an angle of 20° to the vertical, the unit being arranged in an offset position in a rectangular glass tank containing the corrosive liquid. The object of this arrangement is to avoid a vortex in the liquid, such as would set up a complicated and ill-defined state of motion over the surface of the specimen. The tank is supported on a wooden base-board, fitted with battens to hold the tank in the correct position. The rotor is designed to permit ease of assembly, facilitating replacement of individual specimens during the progress of a test. Each specimen is usually insulated from the others and from the steel spindle, although if desired the specimens can be inter-connected within the holder.

The only part of the specimen exposed to the solution is the flat prepared face, the edges and back being coated with chlorinated rubber to avoid rusting by any moisture gaining access to the inside surfaces of the holder. The joints between the ebonite cover-plates and the faces of the holder are made water-tight with rubber washers, thin grease-proof paper being inserted between the rubber and the holder to prevent any possible corrosion due to contact with the rubber. By the use of glass for the tank and ebonite for other parts, and by placing the spindle bearing external to the corroding liquid (*see* Fig. 1), contamination of the liquid, other than from the specimens themselves, is avoided. The tank is fitted with a thin ebonite sheet cover to protect the bearing and the underside of the motor from splashing by spray thrown up from the liquid. An ebonite ring round the spindle further protects the bearing from splashing.

In order to maintain the temperature of the liquid (sea water or salt solutions have normally been used) at 25° C. ± 1° C. (the temperature adopted in most of the tests), it is necessary to pass a regulated supply of cold water from the mains through a simple cooling tube, otherwise the continual churning leads to a

considerable rise in temperature. The level of the liquid and depth of immersion of specimens is maintained as nearly constant as possible; the volume of liquid (approximately 32 litres) varies slightly in different tests owing to small differences in cross-section of the glass tanks. Replacement of solution is usually made at 7-day intervals, although 14 days was adopted in the first series of tests (Part II). The speed of rotation employed in most of the tests to date has been 1500 r.p.m. (equivalent to 20 knots peripheral velocity) but a few experiments have been conducted at 2000 r.p.m. At 1500 r.p.m. there is much turbulence in the liquid and consequently very thorough aeration. The speed is checked twice daily by means of a stroboscope disc mounted on top of the motor spindle and illuminated by a neon lamp, or (when available) by fluorescent room lighting connected to the 50 cycle/sec. A.C. supply. The speed is adjusted, when necessary, by regulating a rheostat in series with the armature windings of the ½-h.p. driving motor, until the black segments on the stroboscope disc appear stationary. The rotation is continuous, day and night; at intervals specimens may be removed and replaced to form a series that will furnish a satisfactory corrosion/time curve. Corrosion is determined by loss of weight and depth of penetration, after removal of corrosion products.

The apparatus lends itself to modifications of technique; for example, the use of specimens in the form of a continuous ring or tube, or the introduction of baffle plates in the water, to meet special conditions of corrosive environment. In the early stages of the present work, specimens were used in the form of rings, 12·7 cm. (5 in.) dia. and 1·0 cm. wide, cut from mild-steel tube. The behaviour of galvanized steel cable has also been tested, using a suitably modified specimen holder.

PART II—ACCELERATED LABORATORY TESTS ON SHIPS'-BOTTOM COMPOSITIONS

The following account deals with the application of the high-speed rotor apparatus to the testing of a series of proprietary ships'-bottom compositions; the tests were carried out in consultation with the Marine Corrosion Sub-Committee and the Admiralty Corrosion Committee. The 30 paint systems covered by the report correspond with those investigated jointly by these Committees in their first series of marine tests[4] in Plymouth Sound (in which much larger specimens were carried on a specially constructed raft), except that several systems which had given poor results in the raft tests were omitted from the present series. The rotor accommodation at Chemical Research Laboratory (C.R.L.) originally provided for the examination of not more than eight paints at one time* (this is now increased to 18); because of the accelerated nature of the test, the experiments need not normally be continued for more than 50 days—the period adopted in the present series. This period (which the evidence suggests might have been further reduced without prejudice to the order of merit) may be compared with that of 29 weeks in the Plymouth raft tests.

Evaluation of the results has been based on visual evidence, supplemented by determinations of loss in weight of the basis metal; the "ratings" obtained by the two methods have, in the main, agreed well, both with each other, and with the ratings yielded by the Plymouth raft tests. It should be noted that each system comprises an underlying anti-corrosive paint (applied usually in two coats) followed by an anti-fouling preparation. In the Teddington experiments there are no means of assessing resistance to fouling, except in respect of the mechanical durability of the anti-fouling component under the conditions of the tests; the main criteria are, therefore, the "mechanical" behaviour of the paint coatings and the extent of corrosion on the underlying metal.

EXPERIMENTAL TECHNIQUE

Preparation and Painting of Specimens

Before painting, the mild-steel specimens (cut from a ship's plate of Admiralty MS steel) are pickled in 15% sulphuric acid (containing 0·05% of di-ortho-tolylthiourea) at 40° C., brushed with a bristle brush in cold water, washed with hot water and allowed to dry in the air, and finally scratch-brushed with a wire brush.† This leaves the metal with a bright, though roughened, surface. For painting, the specimens are mounted in a specially constructed "painting frame" (*see* Fig. 5); this comprises a vertical slotted steel plate, in which the specimens are held with their surfaces flush with that of the plate. In this way paint can be applied with a good sweep of the brush over a reasonable (defined) area, thus overcoming objections associated with the painting of small areas. For each coat, 7 g. of paint is weighed into a dish and is applied with a 2-in. bristle brush to an area 10 in. sq. (or in some cases 2 g. of paint to an area 5 in. sq.), including the area of the specimens undergoing treatment. An appreciable amount of paint is absorbed by the brush, so that less than 7 g. is transferred to the metal—the actual amount varying according to the properties of the paint. The second (anti-corrosive) coat is applied after an interval of 27 hours, the anti-fouling after another 27 hours, and the specimens immersed after a further 20 hours. The specimens are weighed (1) before painting, (2) after the application of the second anti-corrosive coat, and (3) after the anti-fouling coat, time being allowed for drying in each case. The weight of dry paint ranges normally from 30 to 70 mg. per specimen for the two anti-corrosive, and from 15 to 50 mg. for the anti-fouling, coats.

A selection of typical data is given in Table I, where (as throughout the present paper) the various paint systems are represented by code letters. In the last two columns a comparison is made between the average weight of dry paint per sq. in. on C.R.L. and

* Assuming that only one paint is tested on each rotor, the most sound procedure.

† This treatment is the same as that originally adopted by Dr. J. C. Hudson in preparing specimens for the Corrosion Committee Raft Tests.

Table I

WEIGHTS OF DRY PAINT APPLIED TO INDIVIDUAL SPECIMENS IN REPRESENTATIVE PAINT SYSTEMS

C.R.L. Rating	Code Letter	Wt., 2 A.C. Coats (Dry), mg.					Wt., A.F. Coat (Dry), mg.					Total wt., Dry Paint, mg.					Av. wt., Dry Paint, 2 A.C. Coats, mg./in.²	
																	C.R.L.	Raft
Very good	*Kc*	43	33	31	36	76	65	42	48	41	57	108	75	79	77	133	44	43
	Kb	41	38	48	36	49	26	28	27	23	30	67	66	75	59	79	43	44
	Ka	40	50	45	39	22	24	24	32	34	36	64	74	77	73	58	39	43
	Na	40	51	50	43	65	44	48	56	55	50	84	99	106	98	115	50	37
Good	*Ra*	55	61	43	46	60	10	13	15	13	16	65	74	56	59	76	50	37
	Qa	50	35	58	41	49	51	43	33	50	38	101	78	91	91	87	47	72
	Aa	30	35	38	43	38	22	25	23	24	22	52	60	61	67	60	37	75
	Fc	52	58	54	50	47	32	30	39	43	25	84	88	93	93	72	52	76
	Ca	47	28	32	27	13	17	12	10	12	6	64	40	42	39	19	29	80
Moderate	*Ca*	46	40	48	47	46	25	26	24	23	23	71	66	72	70	69	45	50
	Ba	25	27	30	25	32	43	26	28	32	27	68	53	58	57	59	28	45
	Ia	46	52	52	55	43	11	15	10	20	6	57	67	62	75	49	50	77
Bad	*Ma*	88	55	77	72	70	33	40	29	34	27	121	95	106	106	97	72	90
Very bad	*Cb*	21	29	29	26	27	14	22	15	17	18	34	51	44	43	45	26	50
	Ib	68	62	67	67	71	19	21	20	19	18	87	83	87	86	88	67	93
	Sa	54	64	72	40	52	41	42	42	35	35	95	106	114	75	87	56	77
	Da	21	16	23	20	29	16	16	19	12	20	37	32	42	32	49	22	33

raft specimens respectively. For the four paints in the first group the values are closely similar in both series. Usually, however, C.R.L. specimens carried less paint (sometimes less than half the weight per square inch as compared with the corresponding Plymouth raft specimens). This arises, no doubt, from the very different conditions of painting at Plymouth as compared with C.R.L. The intervals between the application of paint coats, also between application of anti-fouling coat and subsequent immersion at Plymouth, were usually very different from the intervals observed throughout the C.R.L. tests. Nevertheless, as will appear later, these differences do not appear to have affected appreciably the relative ratings of the paints.

Corrosion Experiments

Each experiment includes, at the outset, six specimens, five of which are painted, the sixth being exposed in the pickled and scratch-brushed condition. One painted specimen is left with the paint undisturbed ; the remaining four are further treated by scraping paint from an area in the centre of the specimen to leave a clear-cut bare patch or " holiday " measuring 5 mm. square. The object of the "holiday" is to determine whether the absence of paint from a small area will lead to increased local attack and/or encourage stripping of the paint from the adjacent surface.

The method of holding specimens in the rotor apparatus has been described. All the tests now under discussion were carried out at speeds of 1500 r.p.m. (20 knots peripheral velocity) with replenishment of solution (natural or artificial sea water) at 14-day intervals. (In later series a 7-day interval was adopted.) Usually an experiment is continued for 50 days, a specimen with holiday being removed and replaced at three intervals, so that finally the complete set available for examination comprises nine specimens ; seven of these (with holiday) represent respectively 8, 14, 22, 28, 36, 42, and 50 days' exposure ; in addition there is one fully painted and one unpainted specimen exposed for 50 days.

A preliminary experiment was duplicated with natural sea water* and with an artificial sea water containing all the principal ions in the concentrations as found in the natural water. Satisfactory agreement (in respect of the behaviour of the paint system under test) having been obtained, all the remaining tests, because of war-time difficulties† in obtaining further supplies of natural sea water, were carried out in the artificial solution. This was made up from salts dissolved in distilled water in the proportions shown below. The *p*H of the solution ranges from 8·6 to 8·2, after coming into equilibrium with the air, and is stable within 0·1 during use.

Salt	Anhydrous Salt per Litre of Solution, g.
NaCl	27·26
$NaHCO_3$	0·11
KCl	0·69
KBr	0·09
$CaSO_4$	1·29
$MgCl_2$	3·51
$MgSO_4$	1·84

Evaluation of Results

It had originally been intended to supplement visual examination for all specimens at the end of the test

* This experiment (with paint system *Na*), also another experiment with paint system *Kb*, was carried out for 100 days.

† The tests were carried out in 1940.

Table II

C.R.L. ROTOR TESTS OF SHIPS' COMPOSITIONS

5-in. dia. rotor, speed 1500 r.p.m. (peripheral velocity 20 knots), at 25° C.

"C.R.L. Rating" (Order of Merit from Visual Examination) after 50 days

The "Plymouth Rating," given for comparison, refers to the mechanical condition of the paint after 29 weeks' immersion in Plymouth Sound.

Code Letter	Plymouth Rating	Visual Observations
		C.R.L. Rating: Very Good
Kc	V.G.	A.F. began to strip from A.C. coats at 42 days. No noticeable corrosion except at, and around, "holiday."
Kb	V.G.	A.F. began to strip at 72 days (100-day test). Slight blistering at 72 days. No noticeable corrosion until 72 days.
Ka	V.G.	A.F. began to strip from A.C. coats in 28 days. Slight blistering between 36 and 50 days. Very little rusting.
Na	G.	A.F. began to strip from A.C. at 22 days; completely stripped in 36 days. Slight blistering in 42 days. Slight rusting after 42 days.
Ha	M.	A.F. almost entirely stripped from A.C. at 50 days. A peculiar kind of blistering which did not lead to any corrosion up to 50 days. "Holiday" protected completely from rusting.
		C.R.L. Rating: Good
Ra	V.G.	A.F. began to strip in 22 days (A.C. and A.F. similarly coloured and difficult to distinguish) and almost complete in 42 days. Rusting noticeable after 22 days and increased slowly.
Qa	V.B.	A.F. began to strip from A.C. after 28 days and almost gone after 50 days. Flaking and rusting began in less than 8 days and spread slowly, some paint left after 50 days.
Aa	G.	A.F. began to strip in 28 days and practically gone after 50. No blistering or flaking for 14 days, but slight corrosion, due to crumbling, which slowly increased until much of the paint gone after 50 days.
Fc	B.	A.F. began to strip from A.C. after 22 days. Flaking began after 14 days and gradually extended, but after 50 days more than half paint left.
Oa	G.	A.F. began to fail in 22 days, almost gone after 50. Paint failed by crumbling rather than blistering or flaking. Rusting became noticeable after 14 days, or a little less. Slight blistering after 36 and much of paint gone after 50 days.
		C.R.L. Rating: Moderate
Ca	V.B.	A.F. coat began to strip after 14 days, second coat began to strip from first coat in 14 days, also a little stripping of all 3 coats in 14 days. Rusting noticeable after 8 days. Much flaking, leading to steadily increased rusting, but some of two A.C. coats left after 50 days.
Ba	V.B.	A.F. coat began to strip after 14 days. Flaking and crumbling in 8 days producing corrosion. Rusting seemed to increase only slowly, even when much of paint apparently had gone, after about 50 days.
Ia	B.	A.F. began to strip in 14 days. Blistering after 14 days, followed by flaking. Rusting evident after 22 days. More than half paint left after 50 days.
		C.R.L. Rating: Bad
Ma	V.B.	A.F. stripped from A.C. in 22 days, but heavy general flaking and rusting in 8 days.
Fb	V.B.	A.F. indistinguishable from A.C. Blistering, flaking and rusting in 8 days.
Wb	V.B.	Widespread flaking and rusting after 8 days.
Sb	V.B.	Similar, but remainder of paint very friable.
		C.R.L. Rating: Very Bad
Cb	M.	Most of paint disappeared and rusting widespread after 8 days. This paint was fairly good at 1000 r.p.m. but failed badly at 1500 and 2000 r.p.m.
Sa	V.B.	Paint failure and rusting, at end of 8 days, so bad that no distinction can be made. Shorter test periods would be required for rating these paints.
Wa	V.B.	
Da	V.B.	
Va	M.	
La	B.	
Ib	M.	
Ja	V.B.	
Ta	B.	
Vb	B.	
Ga	V.B.	
Fa	V.B.	

Note. *Hb* could not be rated owing to variability of flaking among the eight specimens.

with a quantitative determination of corrosion in the underlying metal; *i.e.*, by measurement of loss of weight and depth of penetration, after removal of rust and adhering paint. So much information, however, was yielded by the visual results—particularly in respect of the condition of the coating—that the preservation of the specimens, in the condition as dismantled, was extremely desirable for the purpose of future reference. By way of compromise, all unpainted specimens, and also the 50-day specimens with holiday, were cleaned and weighed, whilst the remainder (50-day fully painted specimens and shorter-period specimens with holiday) have been preserved.

EXPERIMENTAL RESULTS AND DISCUSSION

Results of Visual Examination

Particular account was taken of the areas still covered by paint and of the condition of the paint (*e.g.*, stripping of anti-fouling coat, presence of blistering, incipient flaking, etc.) especially at the edges of "holidays." The condition of the metal was noted at exposed places, both at the original holiday and at any areas from which the paint had disappeared. For example, with a very bad paint the outline of the holiday becomes obscured—sometimes almost vanishing; the still adherent paint may be blistered and may show incipient flaking, and the uncovered metal may be badly rusted. On the other hand, a very good paint will still show the sharply defined outline of the holiday and the surface will be free, or relatively free, from blistering and flaking. Taking these factors into account, it was found possible to arrange the paint systems in order of merit; first in five well-defined groups (following the Plymouth scheme, these comprise "Very Good," "Good," "Moderate," "Bad," "Very Bad"), and then in further divisions within each group. In Table II

Table III
C.R.L. ROTOR TESTS OF SHIPS' COMPOSITIONS (CONDITIONS AS IN TABLE II)

Gravimetric results after 50 days: painted specimens with "holiday", and unpainted "blank" specimens

"Per cent loss (Plymouth raft)" in column VI refers to data after 29 weeks' immersion in Plymouth Sound.

Code Letter	Loss, g.	Loss, Unpainted "Blank," g.	Loss, "Blank," %*	Loss, Unpainted Steel, %†	Loss, (Plymouth Raft),‡ %
I	II	III	IV	V	VI
Hb	0·117	0·773	15·1	4·5	4·5
Ha	0·127	0·424	30	5	0
Ka	0·148	1·284	11·6	6	No figure
Kc	0·164	1·182	13·9	6·5	5
Na	0·298	1·879	15·9	12	12
Qa	0·481	1·505	32	19	29
Ra	0·501	2·843	17·6	19·5	5
Fc	0·536	1·348	39·8	21	21
Fb	0·539	1·159	46·5	21	31·5
Ma	0·649	1·426	45·5	25·5	52
Aa	0·688	2·831	24·4	27	7
Va	0·713	1·812	39·4	28	38
Oa	0·715	2·589	27·6	28	9·5
Ia	0·759	2·123	35·2	29	20
Ca	0·760	1·670	45·5	30	42·5
Ba	0·827	1·868	44	32·5	38
Da	0·837	1·579	53	33	64·5
Vb	0·877	1·803	48·5	34·5	41
Sa	0·882	1·595	55·5	34·5	43
Fa	0·939	1·790	52·5	37	49·5
Cb	0·973	2·081	47	38	17·5
La	1·048	2·416	43·5	41	22
Ga	1·070	1·527	70	42	46
Wa	1·081	2·050	53	42·5	52·5
Wb	1·101	1·950	56·5	43	69
Sb	1·251	2·251	55·5	49	72
Ta	1·417	1·934	73·5	55·5	25·5
Ja	1·866	1·502	124	73	53·5

* Calculated as percentage of the loss on unpainted "blank" steel included in the same experiment.

† Calculated on loss of unpainted steel in 50 days in a separate experiment.

‡ Calculated on loss of unpainted steel exposed concurrently on the raft.

the paint systems are arranged in the C.R.L. order of merit, the grouping or rating in the Plymouth raft tests being also shown. The "Plymouth ratings" are those supplied by Dr. I. G. Slater (Admiralty) on the basis of the mechanical condition of the paints after 29 weeks' immersion in Plymouth Sound; they do not take into account fouling and they are comparable therefore with the results of the present tests in which fouling is absent.

The outstanding conclusion from Table II is the general similarity between the orders of merit in the laboratory and raft tests. Paint systems near the top and near the bottom correspond closely in the two lists. Occasional differences are to be expected, bearing in mind the difficulties of assessing ratings visually. Several of the more marked discrepancies are probably significant and will be discussed later in the light of the gravimetric results (*see under* "Comparison of Ratings at C.R.L. and Plymouth," p. 253). The observations recorded in Table II show that anti-fouling coats strip from the underlying anti-corrosive coats in relatively short periods under conditions of rapid motion. For all but the "Very Good" and "Good" systems appreciable breakdown and rusting occurs within 8 days and spreads rapidly. A rough classification of the paint systems is thus possible after only a week's exposure under the conditions of the test.

Gravimetric Results

Gravimetric results for the unpainted "blank" specimens and the 50-day specimens with holiday are given in Table III for each paint system. The paints are listed in increasing order of weight loss for the painted specimens (*see* column II). The figures in column III show large variations in the loss of weight of the unpainted specimens in different experiments. Since the unpainted specimen in each set is not in metallic connection with the five painted specimens in the same holder it appears that the rate of corrosion of bare steel is affected by the nature of the material passing into solution from adjacent paint films. This effect is exaggerated in the present tests because the sea water was renewed only once a fortnight. It is possible, however, that in the case of ship's plate moving through the sea, the dissolution of the paint constituents may have some similar effect on the corrosion rate of adjoining areas of bare steel. In separate experiments it has been found that unpainted pickled mild steel in artificial sea water shows an average loss of 2·55 g. in weight in 50 days. The figures in column III show that most paints have an inhibiting effect on the corrosion of exposed bare steel. The effect is most marked with paints *Ha* and *Hb* which contain large proportions of metallic zinc in the anti-corrosive coats, and is appreciable with *Ka* and *Kc* (containing metallic aluminium) and *Fb* and *Fc* (containing white lead).

Column IV gives the percentage loss, taking as basis the loss of the corresponding unpainted "blank" specimen (figure in column III) included in the same experiment. In column V is given the percentage loss, taking as basis, for all paints, the figure of 2·55 g.—the loss of unpainted steel in a separate experiment in which no painted specimens were included. For comparison, figures are included in column VI for the percentage loss in the corresponding raft tests, calculated from data kindly supplied by Dr. J. C. Hudson.* Table III includes all paint systems from Table II with the exception of *Kb* and *Ib*, for which no gravimetric results at 50 days are available.

* Private communication, 18th February, 1941.

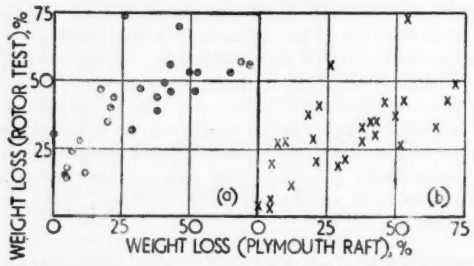


Fig. 2—Correlation between Corrosion Losses of Painted Steel in Rotor Tests and Raft Tests. Per cent loss in Rotor Tests based on loss of unpainted specimen (*a*) in same test, (*b*) in separate test

The results are illustrated graphically in Fig. 2. On the whole, and particularly with the best paints, the agreement with the Plymouth percentage loss is better in column V than in column IV. This is confirmed by a mathematical analysis of the results, kindly carried out by Mathematics Division, National Physical Laboratory. The best estimates of the correlation between rotor and raft test results, together with 95% limits, are given as follows :

Correlation between columns IV and VI
$r = +0{\cdot}507$, limits $+0{\cdot}150$, $+0{\cdot}747$.
Correlation between columns V and VI
$r = +0{\cdot}645$, limits $+0{\cdot}344$, $+0{\cdot}826$.
Correlation between columns II and III
No evidence of any correlation.

In this analysis, specimen *Ka* has been omitted, since no figure is available for the raft test.

Generally speaking, the percentage losses in the laboratory and raft tests are very similar, notwithstanding that the actual corrosion rates (loss of weight per unit area per day) are about 30 times as great in the laboratory as in the raft tests. (Loss of paint is about 10 times as rapid as on the raft.)

Comparison of Ratings at C.R.L. and Plymouth

A summary has been made in Table IV of the ratings, visual and gravimetric, in the raft and laboratory tests. The paint systems are listed in the order of merit (visual) as given by the raft tests, except that *Ha* has been placed in the " Very Good " class on the basis of the gravimetric rating (since this is in excellent agreement with the C.R.L. ratings, and experience suggests that this paint system is very difficult to appraise visually). Examination of Table IV shows that when all the methods of rating are taken into account the agreement between the laboratory and raft tests is more complete than would be deduced from Table II, based on visual observations only. The only serious discrepancies are with *Cb* (worse at C.R.L.), possibly *Fc* and *Ca* (both better at C.R.L.), and particularly *Qa* (much better at C.R.L.). These differences may well be due to the very different conditions in the laboratory tests as compared with those of the Plymouth raft tests, more especially in respect of the rapid motion (corresponding to a linear speed of 20 knots*) and the higher temperature (approximately 25° C. or 77° F.). Both these factors must contribute to the greatly increased rate of corrosion in the laboratory to which reference has already been made. It is reasonable, however, to suppose that they will also lead to specific differences, depending upon the characteristics of the paint under investigation. Thus, a paint that is particularly susceptible to the influence of movement, similarly one that is affected by high temperatures as in tropical waters, will show an increased tendency to break down under the conditions of the rotor tests (*vice versa* for paints especially resistant to these influences). Further work, including tests under actual cruising conditions, will be necessary before these suggestions can be adequately confirmed.

Other factors, such as shape and size of specimen, thickness and method of applying paint coating, time of drying, etc., which may be expected to lead to differences in the conditions of the laboratory and raft tests respectively, do not appear to have affected appreciably the relative ratings of the paints at C.R.L. and Plymouth. This, fortunately, shows that the relative behaviour of these broadly differing paint systems, within the limits of the conditions operating in these tests, is determined mainly by the nature of the paints themselves as distinct from accessory factors connected with the coatings and the specimens to which they are applied.

From the results just described it was concluded that the high-speed rotor apparatus affords a rapid and convenient method of assessing the value of paint systems intended for use on submerged metals.

* Owing to the high degree of turbulence, the conditions in the rotor test may be more severe than on the average surface of a ship's plate moving through the sea at 20 knots.

Table IV

COMPARISON OF RATINGS AT PLYMOUTH AND C.R.L.

Plymouth rating (visual) is that given by Dr. I. G. Slater on the basis of mechanical condition of paints after 29 weeks' immersion at Plymouth. Plymouth rating (gravimetric) is that given by Dr. J. C. Hudson, based on loss of weight after removal of paint.

Code Letter	Plymouth Raft		C.R.L. High-Speed Rotor		
	Visual	Gravimetric	Visual	Gravimetric (1)*	Gravimetric (2)†
Ka	V.G.	No figure	V.G.	V.G.	V.G.
Kc	V.G.	4	V.G.	V.G.	V.G.
Ra	V.G.	5	G.	G.	G.
Ha	M.	1½	V.G.	V.G.	G.
Hb	Not rated	3	Not rated	V.G.	V.G.
Aa	G.	7	G.	M.	G.
Na	G.	9½	V.G.	G.	V.G.
Oa	G.	8	G.	B.	G.
Cb	M.	11	V.B.	V.B.	B.
Va	M.	19½	V.B.	B.	M.
Fc	B.	13	G.	M.	M.
La	B.	14	V.B.	V.B.	B.
Ta	B.	16	V.B.	V.B.	V.B.
Vb	B.	22	V.B.	V.B.	B.
Ba	V.B.	19½	M.	V.B.	B.
Ca	V.B.	23	M.	B.	B.
Da	V.B.	31	V.B.	V.B.	V.B.
Fa	V.B.	27	V.B.	V.B.	V.B.
Fb	V.B.	18	B.	M.	B.
Ga	V.B.	25	V.B.	V.B.	V.B.
Ja	V.B.	30	V.B.	V.B.	V.B.
Ma	V.B.	28	B.	M.	B.
Qa	V.B.	17	G.	G.	G.
Sa	V.B.	24	V.B.	V.B.	V.B.
Sb	V.B.	33	B.	V.B.	V.B.
Wa	V.B.	29	V.B.	V.B.	V.B.
Wb	V.B.	32	B.	V.B.	V.B.

* Gravimetric (1) is rating based on loss of weight of painted specimen (with holiday).
† Gravimetric (2) is rating based on loss calculated as percentage of loss of unpainted " blank " specimen in same experiment.

PART III—COMPARATIVE TESTS OF " FORMULATED ANTI-CORROSIVE PAINTS " (EFFECT OF PIGMENT)

Tests were carried out with the rotor apparatus on six paint systems selected from the first series of

Table V
WEIGHTS OF DRY PAINT

The weights given are the average figures for eight specimens coated with the same paint. Figures for individual specimens varied within about ± 20% of the mean.

No. of Paint	Av. wt. of Paint, mg./sq. in.		
	2 A.C. Coats	A.F. Coat	Total
11	268	83	351
32	201	107	308
48	104	83	187
64	123	96	219
76	74	111	185
80	62	94	156

anti-corrosive paints formulated by Fancutt and Hudson[5] in their work for the Marine Corrosion Sub-Committee. The laboratory test results provided further evidence of the correlation between the order of merit of paint systems as given by the rotor and raft tests.

SPECIMENS

As in earlier series, specimens of ships'-plate steel were pickled in inhibited 15% sulphuric acid at 40° C., followed by washing and wire-brushing. The surface of each specimen was recessed 15/1000 in. below the periphery of the rotor in order to avoid the possibility of the outer surface of a thick paint film projecting beyond the rotor. This usually reduces the rate of breakdown of a paint, but it provides a more legitimate test for coatings of varying thickness.

DESCRIPTION OF PAINTS

Each paint system comprised two coats of anti-corrosive and one coat of anti-fouling paint—the formulated composition AF 1/43 was common to all the systems. Of the anti-corrosive compositions, four were based on the same modified phenol-formaldehyde resin/stand-oil varnish, having the following analysis :

Modified phenol-formaldehyde resin*	20·0%
Stand oil	40·0%
White spirit	39·3%
Lead–manganese–cobalt driers ...	0·7%

The pigmentation was varied to give the following paints :

Paint No. 11	%	Paint No. 32	%
Red lead	37·3	White lead ...	13·6
White lead ...	21·1	Basic lead sulphate	27·2
Witherite... ...	16·5	Burntisland red...	27·3
Asbestine... ...	2·5	Varnish	23·5
Varnish	14·0	Naphtha... ...	7·2
Naphtha	7·8	Dipentene ...	1·2
Dipentene ...	0·8		

Paint No. 48	%	Paint No. 64	%
Burntisland red ...	22·3	Burntisland red...	37·6
Aluminium ...	5·6	Barytes	14·2
Zinc oxide ...	28·0	Zinc dust ...	9·4
Varnish	31·5	Asbestine ...	3·1
Naphtha	11·1	Varnish	27·5
Drier	1·5	Naphtha ...	6·8
		Dipentene ...	1·3
		Drier	0·1

* The particular resin used was Bedesol 66 (Imperial Chemical Industries, Ltd.).

Two anti-corrosive paints were selected from a series prepared by Bakelite, Ltd. These represented combinations of pigment mixtures, suggested by Fancutt and Hudson, with water and alkali-resistant varnishes based on 100% phenolic-resins suggested by the firm. The medium had the following composition : Bakelite resin No. R254, 20% ; linseed oil, 20% ; tung oil, 20% ; white spirit, 40%. The pigmentation was varied to give the following paints :

Paint No.:	76/1	76/2	80/1	80/2
	%	%	%	%
Varnish	44·8	39·0	45·5	41·0
Burntisland red ...	...	...	41·0	49·2
Zinc chromate ...	32·3	37·4	...	...
Asbestine	8·1	9·3	...	...
Thinners				
White spirit	14·3	13·9	13·2	9·7
Xylol	0·1	0·1	0·1	0·1
Butyl alcohol	0·1	0·1	0·1	0·1
Guaiacol	0·1	0·1	...	...
Driers				
Pb–Co–Mn naphthenates	0·2	0·1	0·2	0·1

The anti-fouling paint AF 1/43, used in these tests, was composed of :

		Non-volatile medium	
Toxins		Heavy litho varnish ...	4·5
Cuprous oxide...	16·2	Congo ester ...	1·5
Mercuric oxide	8·1	Rosin	9·1
Secondary pigments		Green oil ...	2·5
Burntisland red	23·9	*Thinners*	
Asbestine ...	14·6	Naphtha ...	12·3
Calcium sulphate	2·9	Dipentene ...	4·4

PAINTING PROCEDURE

The normal method of painting has been described in Part II. For the present series, however, the procedure was modified in that the amount of paint used was controlled on a volume basis, instead of a weight basis as adopted in the earlier work. It was considered that this procedure was more logical, and it was found that a reasonably thick coating could be applied for all the formulated paints, using 2 ml. of paint for an area 5 in. sq. An appreciable proportion of the paint was of course absorbed by the ¾-in. bristle brush (*cf.* 2-in. brush in earlier tests) used in this work.

The weights of dry paint varied with the type used ; average figures based on eight specimens coated with each paint are given in Table V. It will be noted that the weights (and hence film thicknesses) are appreciably greater than those used in the earlier series of tests (Part II).

RESULTS AND CONCLUSIONS

Each paint system was applied to 6 specimens (2 with central "holiday") which were mounted in the same rotor. Separate tests were carried out for each system. Two specimens were removed at 7 days and replaced by two freshly painted specimens, these being left for the remaining 14 days of the test. Results were therefore available at the end of a test for duplicate specimens exposed for 7, 14, 21 days, and two specimens with "holiday" for 21 days (Table VI). The percentage area from which paint had stripped during the test was estimated visually

Table VI

PERCENTAGE AREA OF PAINT REMOVED IN 21-DAY TESTS

Paint No.	7 days	14 days	21 days	21 days (holiday)
32	Nil	Nil	Nil	Nil
76	Nil	Nil	2 | 82	Nil
48	Nil	30 | 14 (1) | (5)	10 | 49 (14) | (4)	1 | 25 (2) | (2)
11	Nil	Nil | 26	1 | 2	65 | 59
64	76 | 93 (nil) | (5)	36 | 28 (22) | (26)	48 | 93 (49) | (5)	92 | 69 (5) | (21)

by placing a wire grid, with $\frac{1}{16}$-in. squares, over the specimen. The figures in brackets in Table VI represent the areas of anti-fouling paint stripped from the underlying adherent anti-corrosive paint.

The most striking result is that paint No. 32 is clearly superior to the other paints, agreeing with the good behaviour in raft tests conducted by Fancutt and Hudson. These investigators selected paint No. 32 as the most promising prototype paint for further formulations. Apart from paint No. 32 it is not easy to arrange the paints in an order of merit, since the amount of paint stripped was not always greater for longer periods of test. An arbitrary figure of merit was calculated for each paint as follows:

$$\text{Figure of merit} = 3A + 1{\cdot}5B + C + D$$

where A = breakdown in 7 days, B, 14 days, etc.

On this basis the order of merit is:

32 (best), 76, 48, 11, 64 (worst).

The corresponding order taken from Fancutt and Hudson's results for raft tests is:

32 (best), 64, 76 and 11, 48 (worst).

It is notable that paint 64 has given a much better result on the raft than in the rotor test, where it was clearly the worst paint. Probably this paint is specially susceptible to loss of adhesion in conditions of rapid movement such as are reproduced on the rotor but not in raft tests. Fancutt and Hudson concluded that the paint medium was not suited to pigmentation with zinc dust (as used in paint 64), and poor adhesion had previously been observed in rotor tests on certain zinc-rich paints.

Results are not reported in Table VI for paint No. 80, since the test was stopped at 5 days owing to the extremely variable and sometimes rapid stripping of paint from different specimens. It appears that paints of this type, based on 100% phenolic-resin media are intrinsically resistant, but are sometimes liable to sudden loss of adhesion in rapidly moving water. Paint No. 76, almost as outstanding as No. 32, showed 82% loss of adhesion on one 21-day specimen.

PART IV—COMPARATIVE TESTS ON MODIFICATIONS OF ANTI-CORROSIVE PAINT "NO. 173"

Rotor tests have been conducted on several modifications of Paint No. 173.[6] This paint is virtually to the same formulation as Paint No. 32 (*see* Part III of this paper).

DESCRIPTION OF PAINTS

No. 173: The pigmentation comprises 2 parts of basic lead sulphate, 1 of white lead and 2 of extender (equal parts of Burntisland red and barytes); the medium is a modified phenol-formaldehyde/stand oil type.

No. 173/A (or 173/1): Sample of batch made on a large scale at Derby for patch-painting tests by Admiralty and by Dr. Harris (Millport).

No. 173/2: Sample from 100-gal. batch prepared under industrial conditions for full-scale tests on ships.

No. 173/3: Sample from small batch prepared in the laboratory from raw materials used in manufacture of industrial batch.

No. 276: Similar to No. 173, but with oil length shortened to 1 to $1\frac{1}{4}$, *i.e.*, 24 parts "Bedesol 66" to 30 parts of medium stand oil.

No. 277: Similar to 276, but with oil length 1 to $1\frac{1}{2}$, *i.e.*, 23 parts "Bedesol 66" to 33·5 of medium stand oil.

No. 278: Similar to 277 (oil length 1 to $1\frac{1}{2}$) using 23 parts "Albertol resin 209L" to 33·5 of medium stand oil.

No. 174/B: Same pigmentation as No. 173, but in coumarone/litho-varnish medium. (Sample from large batch of paint).

No. 178/F: Similar to 173 and 174, but using 100% phenolic-resin medium. (Sample from large batch of paint).

AF 23H 18/4: Anti-fouling paint containing 18% of cuprous oxide and 4% of mercuric oxide.

AF 28H 24/6: Anti-fouling paint containing 24% of cuprous oxide and 6% of mercuric oxide.

PREPARATION OF SPECIMENS

For the main series of tests pickled specimens (with edges and backs suitably protected) were mounted on a steel frame and, through the kindness of Dr. J. C. Hudson, exposed to the atmosphere for 3 months at the Caernarvon Testing Station of the Marine Corrosion Sub-Committee. On return to Teddington the

Table VII

WEIGHTS OF DRY PAINT

Figures given are averages of duplicate specimens. (Variation between duplicates was usually not greater than 20%, but occasionally reached 100%). Weights shown in mg./sq. in.

Anti-Corrosive Paint	AF 23H 18/4			AF 28H 24/6		
	2 A/C Coats	A/F Coat	Total	2 A/C Coats	A/F Coat	Total
173/1	108	33	141	103	32	135
173/2	108	45	153	116	53	169
173/3	112	45	157	114	49	163
276	138	39	177	129	47	176
277	128	29	157	109	46	155
278	127	35	162	114	36	150
173/1	113	37	150	104	42	146
174/B	92	28	120	90	37	127
178/F	79	27	106	68	38	106
On Pickled and Wire-brushed Surface						
173/1	95	39	134	...	...	...
173/2	68	45	113	...	...	...
173/3	78	51	129	...	...	...

specimens were stored in a cupboard until they were wire-brushed, just before painting. The surface, after wire-brushing, was covered with an adherent layer of rust which appeared to provide a good "key" to the paint.

In order to facilitate comparison with results of earlier rotor tests an additional set of specimens was used in the pickled and wire-brushed (not subsequently weathered) condition for a repeat test of paints 173/1, 173/2, and 173/3 with AF 23H 18/4.

PAINTING PROCEDURE

The six specimens (lettered A to F) of each rotor test were divided into pairs, each pair being painted with a different anti-corrosive, but with the same anti-fouling paint. The method of painting has been described. Table VII gives the average figures for weight of dry paint on the specimens. There are appreciable variations in these weights, but there is not sufficient evidence to decide whether these variations have materially influenced the results.

EXPERIMENTAL TECHNIQUE

Daily visual observations were made on the state of the paint coatings, noting (*a*) blistering, (*b*) removal of anti-fouling from anti-corrosive coats, and (*c*) stripping of the whole paint film from the metal. Tests were discontinued at 50 days, when specimens were removed, washed in running water and dried carefully with a cloth. The percentage area affected by paint breakdown was estimated, using a wire grid with $\frac{1}{10}$-in. squares.

RESULTS AND CONCLUSIONS

Results are summarized in Table VIII. All the anti-corrosive formulations, except 174/B, can be broadly classified as "good" paints; in previous tests with the C.R.L. rotor, only a few proprietary compositions have given better protection against corrosion. None of the paint systems used in these tests has given quite such a good performance as Paint No. 32 (two coats) with AF 1/43 (*see* Table VI). Possibly the superior behaviour, in respect of corrosion, of the earlier system was partly due to the use of a less permeable anti-fouling coat. With anti-corrosives 173/1, 173/2, and 173/3, the paint film appears to strip less readily from the weathered surface, but blisters are rather more numerous (except with 173/2) as compared with the pickled and wire-brushed surface. The worst anti-corrosive paint of the series is 174/B (coumarone/litho-varnish medium), which develops very large blisters. Blistering is most widespread on paints 276, 277, and 278.

The order of merit deduced from the tests is: (Best) 173/1, 173/2, 173/3, 178/F, 276, 277, 278, 174/B (worst). Adhesion of anti-fouling paint AF 23H 18/4 is less satisfactory on paints 276, 277, and 278 than on others.

PART V—METHODS FOR ACCELERATING THE RATE OF DETERIORATION OF PAINT COATINGS

It has been demonstrated (Part II) that the high-speed rotor apparatus provides a reliable and convenient means for accelerating the rate of deterioration of paint coatings. In the work so far described, the speed of rotation of 1500 r.p.m. has been adopted as a standard condition in comparing the relative protective properties of paint systems. Owing to pressure of *ad hoc* work it has not been possible to investigate the rate of breakdown of typical paint systems over a wide range of speeds, although evidence has been obtained that the rate of breakdown usually increases up to the highest speeds (2000 r.p.m.) investigated.

INFLUENCE OF SPEED OF MOVEMENT

Results are summarized in Table IX for tests at speeds of 1000, 1500 and 2000 r.p.m. on six ships'-bottom composition systems. Each system comprised two coats of anti-corrosive and one coat of anti-

Table VIII

SUMMARY OF RESULTS* AT END OF 50-DAY TEST

Paint	AF 23H 18/4			AF 28H 24/6		
	Bare, %	A/F Removed, %‡	Blistered, %	Bare, %	A/F Removed, %	Blistered, %
173/1	...	5·5	20–30	0·5	2·0	15–25
173/2	0·5	4·0	20–30	0·5	2·0	20–30
173/3	1·0	7·5	10–15	0·5	7·0	15–25
276	1·0	25·0	30–40	1·0	5·0	30–40
277	1·0	20·0	30–40	1·0	2·0	30–40
278	0·5	25·0	30–40	1·0	25·0	30–40
173/1	1 spot	25	20	1 spot	10·0	20
174/B	14·0	...	25–30†	2·0	...	25–30†
178/F	ca. 30 pin points	10·0	ca. 30 pin points	ca. 30 pin points	5·0	ca. 30 pin points
On Pickled and Wire-brushed Surface						
173/1	3·0	50·0	10–15	...	...	...
173/2	10·0	4·0	30·0	...	...	...
173/3	8·0	3·0	10·0	...	...	...

* Figures are averages of duplicate specimens.
† Individual blisters large (each covering 0·5 to 1% of painted area).
‡ % of A/F removed indicates percentage of total area from which the anti-fouling coat has been lost, leaving anti-corrosive coats intact.

fouling paint. Although there are many individual exceptions, there is a general tendency for more rapid breakdown to occur at the higher speeds. It should be noted that paint *Kc* shows little deterioration even at 2000 r.p.m. 100-day tests at this speed on paint *Kc* and other proprietary paints now available have confirmed that remarkably good adhesion can be achieved over long periods at high speeds of movement in sea water. Indeed it is necessary to devise tests that will provide a sufficiently high degree of acceleration to differentiate the best available paints in reasonably short test periods. Further work is projected at still higher speeds.

INFLUENCE OF TEMPERATURE

The temperature so far adopted in the rotor tests is 25° C. (77° F.), which represents a considerable increase over that normally prevailing in the sea. It is probable that this rise of temperature appreciably accelerates the rate of breakdown of paint coatings. A few tests on "high-duty" compositions at 1500 r.p.m. and 35° C. have indicated an appreciable acceleration of breakdown as compared with tests at 25° C., using the same speed of rotation. Further work in this direction is contemplated.

PART VI—ASSESSMENT OF PAINT FAILURE IN ROTOR TESTS

ESTIMATION OF "USEFUL LIFE" OF A PAINT SYSTEM

The quantitative assessment of the "failure" of a paint presents a problem of considerable difficulty, particularly when it is desired to compare results obtained at different times or by different observers. In most of the work at Chemical Research Laboratory it has fortunately not been necessary to measure the degree of paint failure with any great accuracy, since only broad classification of paint performance was required. This, incidentally, would seem to apply to most investigations on paint systems.

In the work here described the percentage of the specimen area from which paint has become detached during an arbitrary period of test has been used as a quantitative measure of paint failure.

The "scatter" of results among multiplicate specimens tested simultaneously on the same rotor is often quite large, but this scatter is controlled not only by conditions during the test but also by variations in uniformity of the pickled surfaces employed in these tests, and in the thickness of paint film on individual specimens. The estimated standard deviation for percentage paint failure in typical instances for 6 specimens on the same rotor varies from 6% to 60% of the mean loss. The variation between means of duplicate rotor tests is from 0% to 50% of the grand mean. It is clearly desirable to use 6 (and preferably 12) specimens with a given paint if reasonably accurate assessment of the paint is required. For other reasons (*see* Part II—Gravimetric Results) it is unwise to expose paints of differing types side by side on the same rotor in a common corroding liquid.

In a further comprehensive series of *ad hoc* tests for the Admiralty* during the recent war, using the high-speed rotor technique as already described, it was found convenient to express the useful life of a paint system as the test period in days corresponding with loss of paint from 10% of the specimen area. This method is very convenient and is reasonably sound for paints which fail rapidly in the rotor test ("lives" not more than 50 days). Instances have arisen, however, of paint coatings which are so firmly adherent to the underlying metal that the area of metal exposed may be only a few per cent. after periods of 100 to 300 days. It is then necessary to consider the rate of pitting or penetration of the metal at the small exposed areas. The fact that only 1%, say, of the coating has been removed after 300

* Results incorporated in Tables X, XI, and XII and Fig. 3 are published by permission of the Chief of the Royal Naval Scientific Service.

Table IX

PERCENTAGE AREA OF PAINT REMOVED IN TEST

Paint System	Speed, r.p.m.	Test Period, days							
		8	14	22	28	36	42	50	50*
Da	1500	13	...	27	66	30	85	...	70
	2000	44	69	16	84	31	77	95	80
Kc	2000	4	3	1	1	2	14	1	0
Cb	1000	9	14	15	9	10	17	27	80
	2000	42	95	70	90	95	85	95	100
Bb	1000	15	2	34	5	27	5	10	12
	2000	5	6	12	10	13	12	26	21
Ab	1000	5	5	21	18	41	16	22	18
	2000	100	100	100	100	100	100	100	100
Kg	1000	20	8	35	18	49	18	16	27
	1500	16	...	58	27	38	15	...	38
	2000	11 (1 day)	10	74 (15 days)	45	95 (29 days)	54	68 (43 days)	83 (43 days)

* Completely painted specimens. The remaining specimens were tested after making a central "holiday" (5 mm. square) in the paint film

Table X

DEPTH OF PENETRATION OF CORROSION ON STEEL SPECIMENS USING CHLORINATED RUBBER PAINT PIGMENTED WITH RED LEAD

Test Conditions	Period of Test, days	Depth of Penetration, mm.			
		Face	Edge	Corners	Holiday
2000 r.p.m.	127	0·46	0·36	Nil	0·40
1500 r.p.m., 35° C.	127	0·52	0·50	Nil	0·69

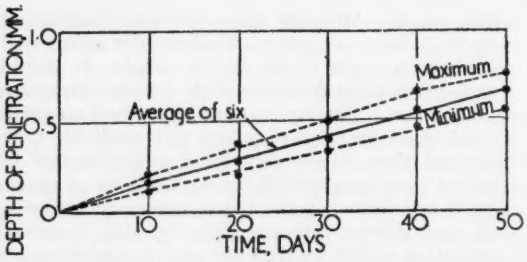


Fig. 3—Depth of penetration/time curve for copper

days indicates that the adhesion is extremely good, but it does not follow that no dangerous pitting has developed.

Measurements of depth of penetration (made with a micrometer gauge) are recorded in Tables X and XI ; a penetration/time curve for unpainted copper is given for comparison in Fig. 3. On steel specimens severe pitting has been observed only rarely ; for example, in association with a red lead–linseed oil primer, or in certain tests conducted at 35° C. or at higher speeds (Table X). With copper there is a greater tendency for localized attack, both on painted and unpainted specimens. The possibility arises that rate of penetration at a small area from which paint has become detached may be accelerated by cathodic action on the surrounding (relatively large) area of intact paint. This does not appear to have occurred in the present series of tests, since the maximum depth of penetration at the " holiday " is very similar (about 0·5 mm.) at a 50-day period for all the paints tested, and slightly less than the corresponding figure for unpainted specimens. (A paint pigmented with graphite provided a notable exception, showing very deep pitting.) Using the figures in Table XI, the average rate of penetration has been calculated for specimens coated with the best paint systems, on the assumption that penetration proceeded at a uniform rate from the time at which paint failure was first observed until the end of the test period. The results (Table XII) show that penetration rates are of the same order as, and often less than, the average rate of $1{\cdot}3 \times 10^{-2}$ mm./day calculated from the slope of the main part of the curve in Fig. 3.

It is evident from Tables X and XI that penetration is usually greatest at points along edges and at corners of specimens, where paint breakdown frequently occurs first. The figures for the face of the specimen are usually much less and should represent the penetration likely to occur on a large surface free from joints and discontinuities.

Consideration of the penetration figures indicates that caution should be exercised in judging the life of a coating on the basis of the period for " 10 per cent. loss." For example, the assignment (on this basis) of a useful life of more than 294 days for a chlorinated rubber paint is somewhat artificial when the metal has become penetrated to depths of from 0·5 mm. to 3 mm. (Table XI).

Table XI

DEPTH OF PENETRATION OF CORROSION ON COPPER SPECIMENS

Paint System	Period of Test, days	Depth of Penetration, mm.			
		Face	Edge	Corners	Holiday
Phenolic Resin Lacquer (pigmented)	329	Nil	2·01	1·51	...
		0·32	1·03	1·69	...
		0·72	0·74	2·01	...
Chlorinated Rubber Paint (pigmented with red lead)	294	Nil	1·08	2·5	...
		Nil	0·68	2·5	...
Clear Lacquer	250	Nil	1·85	2·16	...
		1·43	...	...	1·40
Phenolic Resin Stoving Varnish	138	0·84	1·04	...	...
		0·85	...	...	0·81
Chlorinated Rubber Paint (pigmented with white lead)	50	0·61	1·07	...	...
		0·47	...	...	0·51
Stoving Enamel	50	Nil	Nil	Nil	...
		0·64	...	...	0·45

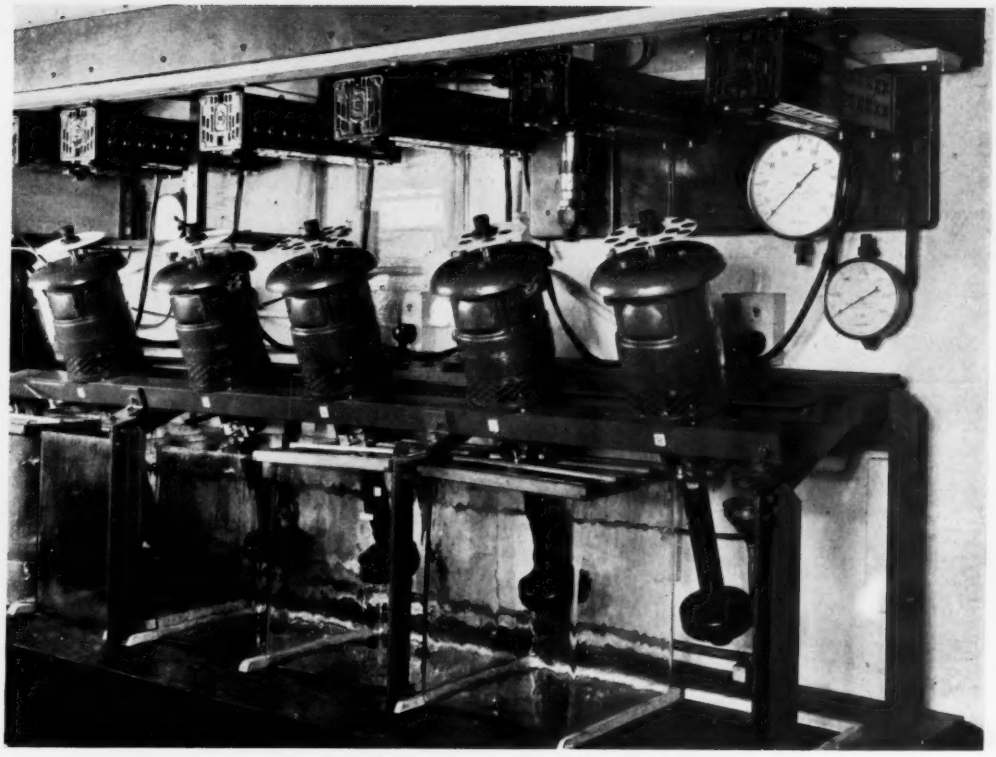
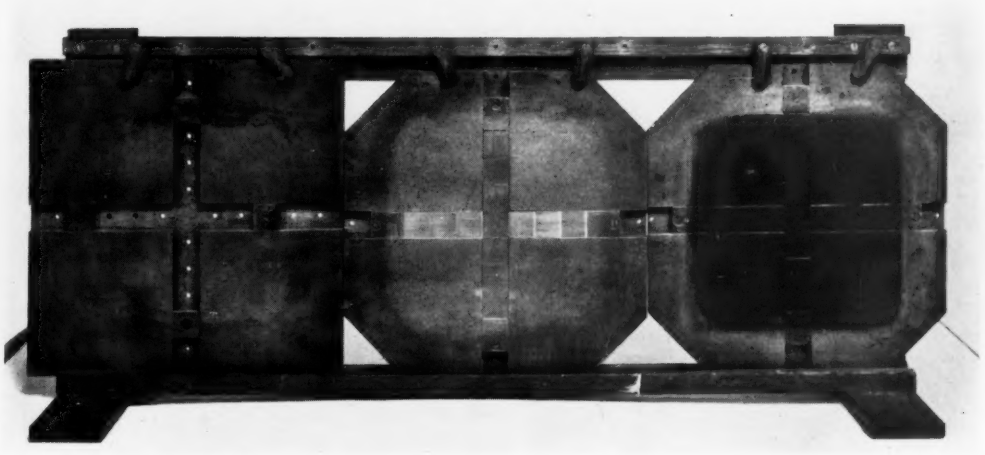
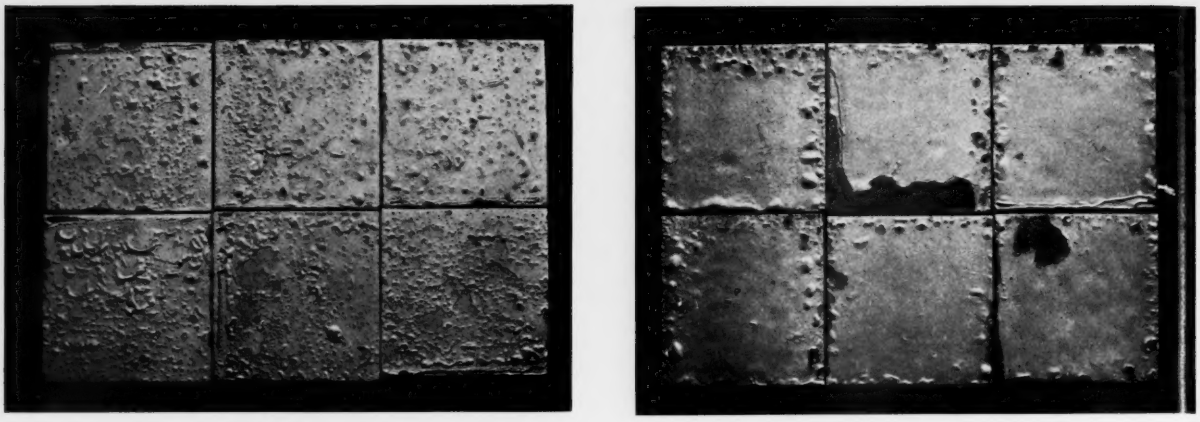


Fig. 4—General view of battery of six rotor units



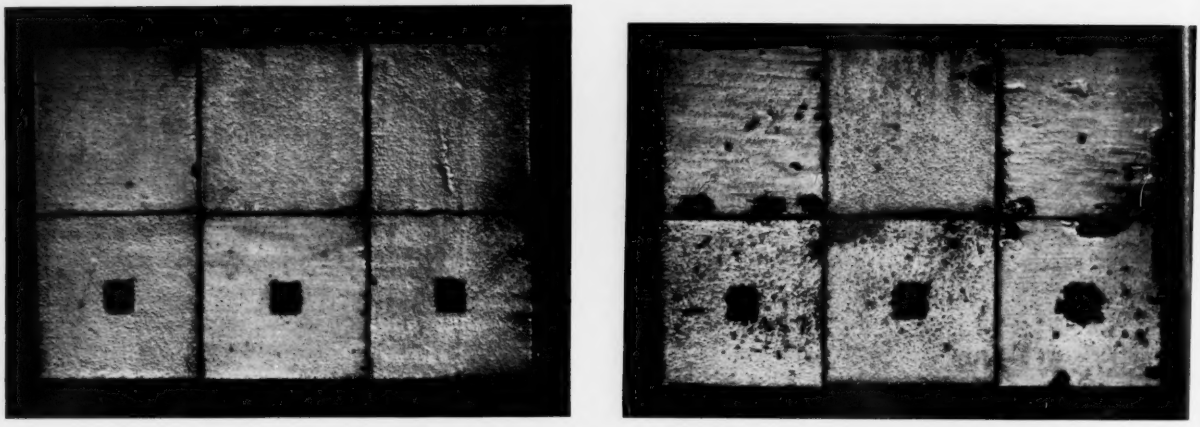
(*a*) (*b*) (*c*)

Fig. 5—Painting Frames : (*a*) without specimens, (*b*) specimens in position, (*c*) specimens after painting



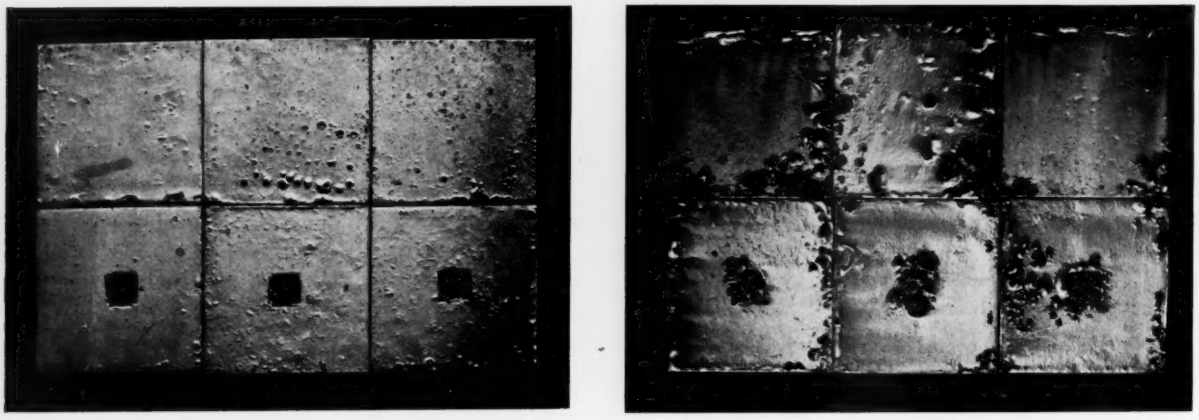
(*a*) (*b*)

Fig. 6—Condition of Paint No. 32 after 21-day tests, (*a*) Distilled water, (*b*) Sea water



(*a*) (*b*)

Fig. 7—Condition of a Chlorinated Rubber Paint after 50-day tests, (*a*) Distilled water, (*b*) Sea water



(*a*) (*b*)

Fig. 8—Condition of a Chlorinated Rubber Paint after 100-day tests, (*a*) Tap water, (*b*) Sea water

MORE REFINED METHODS OF ASSESSING PAINT FAILURE

An alternative method of expressing useful life would be the time in days at which metal first becomes exposed owing to breakdown of the coating. In practice the period for 1% exposure might form a useful criterion. Even this is not always easy to estimate visually, and experience has shown that paints showing slight breakdown at a relatively early stage often deteriorate less rapidly than others showing a later initial breakdown. On the whole, the "relative" lives in service are probably better reflected by the figures for 10% breakdown. Whether the 1% criterion is adaptable for use in rapidly rejecting unsuitable paints is a matter for further enquiry.

Recent work at Chemical Research Laboratory[7] has shown that changes in the electrical properties of painted steel afford a sensitive means of detecting and estimating quantitatively the incidence and development of paint failure. Tests have so far been conducted mainly in quiescent artificial sea water; consequently paint failure develops relatively slowly. Preliminary experiments have shown, however, that in conditions of rapid movement breakdown (with the particular paint used) can be detected electrically in periods of about 6 as compared with about 25 days in quiescent solution. The combination of electrical measurements with the severe exposure conditions of rotor tests is being studied.

MODES OF DETERIORATION OF PAINT COATINGS

An advantage of the rotor test for evaluation of protective coatings is the relative ease with which paint failure can usually be estimated visually. Any serious loss of adhesion is quickly revealed by the rapid removal of paint over areas of 1 sq. mm. upwards, owing to the rapid movement of the specimen and the consequent shearing forces operating across the face of the specimen; the relative contribution of centrifugal force is not known, but no doubt this plays some part.

Loss of adhesion over appreciable areas may occur without any obvious prior blistering or other change in the paint film; this type of failure is observed with certain relatively impermeable films, but it also occurs with other types of paint showing poor adhesion. It has been observed that immediately after the paint has become stripped, the exposed metal surface appears bright or, at most, coated with a thin film. Rusting does not usually commence for a few hours. This suggests that a film is formed by interaction of the paint with the metal surface, conferring some protective properties for a limited period of exposure to sea water. Some confirmation of this has been obtained by electrode potential measurements. Two specimens were painted in the usual way with one coat of an anti-corrosive ships' composition of moderate quality. After 24 hours' drying, the paint was removed in liquid benzene at about 50° C. and the specimens immersed in artificial sea water, together with two similar specimens, freshly prepared (and immersed in hot benzene) but unpainted. The potential/time curves, measured with reference to a saturated KCl calomel half-cell, are recorded in Fig. 9. The less rapid decline in potential of the specimens which had been painted indicates that some degree of protection had been conferred by film-formation.

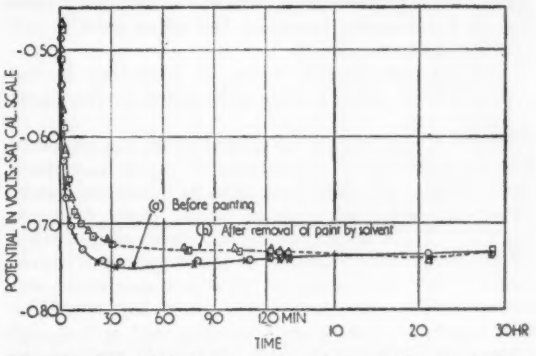


Fig. 9—Potential/time curves for steel (*a*) before painting, (*b*) after removal of the paint by solvent

Blistering

A frequent sign of incipient failure is blistering, this being the usual precursor of flaking in many paints of moderate to good protective properties, although blistering and flaking often occur alongside. In rotor tests blistering of three types has been observed, namely:

(1) Blisters associated with incomplete drying of the paint prior to immersion. The retention of volatile constituents appears to encourage blistering due to slow loss of solvent after immersion or to enhanced osmosis of water,[12, 13, 16] through the relatively open structure of the paint.

(2) Blisters formed by mechanical expansion due to rust formation[9, 10, 11] beneath the paint. These are usually from 1 to 2 mm. dia. and they may be distributed sporadically over the face of a specimen, or concentrated near edges.

(3) Blisters apparently produced by softening and loosening of the paint by alkali formed at cathodic areas.[8-11, 14, 15] These blisters usually occur adjacent to corroding areas at "holidays" or along the edges of specimens. The metal beneath the blister may be bright or may be covered by a thin oxide film. Once the blister has broken, corrosion usually commences on the exposed metal;

Table XII

CALCULATED RATE OF PENETRATION ON PAINTED COPPER

Based on depth of deepest pit and on assumption that corrosion penetrates at a uniform rate from time of first exposure of bare metal until end of test.

Paint System	Rate of Penetration, 10^{-3} mm./day
No paint (50-day test)	1·3
Chlorinated rubber paint (pigmented with red lead)	1·5
Phenolic resin lacquer (pigmented)	0·65
Clear lacquer	1·3

the alkali produced by cathodic action may then spread outwards, loosening the paint over a still wider area.

A further possible cause of blistering is the presence of water-soluble substances in the paint film.[17]

Blister formation due to cathodic alkali is probably less frequent in the conditions of rapid movement characteristic of rotor tests than in quiescent water, owing to rapid dissipation of alkali. Some evidence has been obtained, suggesting that formation of large blisters is more pronounced at lower speeds of movement. Tests are projected in which specimens will be exposed to quiescent water, or at low speeds of movement, to encourage blistering and widespread lifting of the paint, followed by rapid rotation to increase the corrosion rate and to accelerate the stripping of the paint coating.

BEHAVIOUR OF PAINTS IN FRESH WATERS

The rotor test has so far been used mainly for tests of protective coatings immersed in sea water. A few experiments have been carried out in distilled water or (hard) tap water. Certain paints in bituminous media showed greatly superior adhesion in distilled water as compared with artificial sea water. In an extreme case, a bituminous paint that lost adhesion over 25 to 90% of the area in 1 day in sea water showed no loss of adhesion after 50 days in distilled water.

A three-coat anti-corrosive paint system based on paint No. 32 (*see* Part III) was tested in distilled and in artificial sea water for 21-day periods. Fig. 6 shows that blistering and wrinkling (mainly of the third coat) was more pronounced in distilled water, but loss of adhesion was greater in sea water. A chlorinated rubber paint, pigmented with metallic zinc (1 coat) followed by a white lead finishing coat in a similar medium, showed virtually no blistering or other breakdown after 50 days in distilled water (Fig. 7) as compared with appreciable blistering and rusting, mainly in small spots or patches of about 10 sq. mm. in area, after the same period in sea water. Another chlorinated rubber base paint pigmented with zinc chromate and ferric oxide (applied as 2 coats) showed a similar contrast in behaviour in sea water and in tap water respectively. Fig. 8 shows the condition of the paint at the end of 100-day tests.

GENERAL CONCLUSIONS

1. The high-speed rotor apparatus, of which a detailed description is given, provides a convenient and reliable technique for accelerated tests of protective coatings under immersed conditions. The quantitative assessment of paint failure is facilitated in the rotor test by the mechanical removal of paint that has lost adhesion.

2. Good correlation has been established between results of rotor tests and raft tests of ships'-bottom compositions.

3. The rotor test is useful in comparing different modifications of a given paint.

4. Many paints are commercially available, or have recently been developed elsewhere, which show such a high degree of adhesion that more intensive test conditions are required to evaluate the paints in reasonably short periods.

5. An alternative to intensification of test conditions is the development of more sensitive methods of detecting paint failure. An electrochemical technique has proved useful : combination of this with the rotor test may lead to further advances.

Acknowledgments

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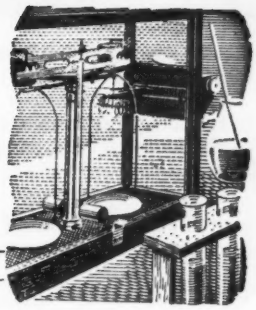

The Thermodynamics of Substances of Interest in Iron and Steel Making from 0° C to 2400° C

By F. D. Richardson and J. H. E. Jeffes

I—OXIDES

SYNOPSIS

A survey is made of the thermal data at present available for oxides of interest in iron and steel making. The free energies of formation of these oxides from their elements are calculated for temperatures up to 2000° C and the results are plotted on a free-energy/temperature diagram. Equations are given for each oxide, and limits of accuracy are proposed. The free energies of formation vary linearly with temperature within the limits of accuracy of the data available. The reason for this, and the limitations and advantages of the straight-line plots are discussed. The advantages of the graphical representation of the results on a free-energy/temperature diagram are considered, and its value in elucidating complex processes and individual equilibria is illustrated by examples. It is shown how these and other problems can be easily solved by the use of a special transparent grid which is superposed on the diagram.

Introduction

To understand any process in which a number of chemical reactions may conceivably be involved it is helpful to be able to separate at a glance those reactions and equilibria which are likely to be important from those which are not. In addition it is desirable to be able to see quantitatively how the system may change as temperature, pressures, and concentrations are altered. In 1944 H. J. T. Ellingham[16] published two diagrams, which went a long way to meeting this need for reduction processes involving metal oxides and sulphides, and reference to his paper is strongly recommended. These diagrams showed the change with temperature of the free energy of formation of oxides and sulphides from their elements, but no indication was given of the particular data used or the probable accuracy of the curves. It is felt that this type of diagram can be particularly useful for consideration of the reactions occurring both in the blast-furnace and in steel refining, though it is, of course, recognized that a full appreciation would require a suitable representation of the kinetics as well as the thermodynamics of the various reactions. There appears, however, to be no ready way of presenting the former, and there are indeed very little accurate kinetic data available. It has therefore been considered worth while to prepare revised free-energy/temperature diagrams for the oxides and sulphides of particular interest in iron and steel making, and for slag constituents and slag compounds. The first of these is presented in this paper. A series of papers is also being prepared showing the more detailed application of this information to the processes of the blast-furnace and of refining, deoxidizing, and desulphurizing steel.

The curves reproduced in Fig. 1 show the variation with temperature of the free-energy change accompanying the conversion of *one gram molecule* of oxygen at 1-atm pressure into the appropriate quantity of oxide. They are based on the best available information and are graded according to accuracy. Although the original papers have been consulted in most cases, the collections of data prepared by K. K. Kelley,[30–34] F. R. Bichowsky and F. D. Rossini,[3] J. Chipman,[7] and M. de Kay Thompson,[55] have been found particularly useful. Care has been exercised in selecting the most concordant sets of results and in incorporating information which has become available since those collections were made. Full details of the data used, the accuracy gradings, and the equations recommended, are given in the Appendix.

THE CONSTRUCTION AND FORM OF THE FREE-ENERGY/TEMPERATURE DIAGRAM

Thermodynamic Equations

As will be seen from the Appendix, three kinds of experimental results were used: (*a*) Direct equilibrium

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Dr. Richardson and Mr. Jeffes are on the staff of the British Iron and Steel Research Association.

measurements, (*b*) thermal data, and (*c*) e.m.f. measurements of appropriate cells.

The values of the free energies of formation, ΔG°_T, were calculated from these three classes by means of the following well-known thermodynamic relationships :

$$\Delta G^\circ_T = -RT\log_e K_T \quad \text{.....(1)}$$

$$\Delta G^\circ_T = \Delta H^\circ_T - T\Delta S^\circ_T \quad \text{.....(2)}$$

$$\Delta G^\circ_T = -nFE^\circ_T \quad \text{.....(3)}$$

where : ΔG°_T = Standard free-energy change at temperature T, expressed in calories, for the reaction involving one gram molecule of oxygen

R = Gas constant (1·986 cal/mol/degree)

T = Absolute temperature ($t°$ C + 273°)

K_T = Equilibrium constant at temperature T of the reaction; expressed in terms of partial pressures in atmospheres for gases, and molar fractions, which are equal to unity, for the pure liquids and solids concerned here

ΔH°_T = The standard change in heat content of the system on reaction at constant pressure at the temperature T. (This is numerically equal to the conventional heat of reaction, but opposite in sign)

ΔS°_T = The standard entropy change for the reaction at the temperature T

F = Faraday equivalent (23,074 cal/V)

n = Number of Faraday equivalents

E°_T = Standard electromotive force of cell in volts at temperature T

The superscript (°) indicates that the function concerned refers to reactants and resultants in their standard states.

Standard States

It is useless to quote the free-energy change for a reaction without defining the conditions of the reactants and resultants—that is, without defining the standard states to which the free-energy change is related. In this connection it is usual to define the standard state for a gaseous component as that at 1-atm pressure, and for a solid or a liquid component as that of the pure phase. This practice has been adopted throughout. In equation (1) the units in which the equilibrium constant is measured determine the standard states for the reactants and resultants. It therefore follows that gas pressures should appear in the equilibrium constant as atmospheres, and concentrations of pure liquid and solid phases as unity.

It follows that in equation (2) the values of ΔH°_T and ΔS°_T must be those for a change from one set of standard states to another at the temperature concerned. This equation provides a method of determining ΔG°_T which is completely independent of equation (1). As is well known, this method can be applied only in cases where ΔH°_T is known at any one temperature and the specific heats of reactants and resultants are known over the range from absolute zero to the highest temperature involved in the calculation. The specific heat is determined either by direct measurement or, in the case of gases, by calculation from spectroscopic data. It is often necessary to use combinations of these methods, *e.g.*, to derive the entropy of a substance at 25° C from thermal measurements and the high-temperature specific heats from spectroscopic data.

Construction of the Curves and Use of the Straight-Line Plots

The curves were generally constructed by plotting the available data and then drawing the best straight lines through them, with appropriate breaks at the phase-change points. When the entropy changes were known the changes of slope were made to correspond with them, within the limits of their probable accuracy.

Since $\delta\Delta G°/\delta T = -\Delta S°$, the slope of any line at any point should give the value of ΔS°_T at that temperature. Furthermore the intercept made by the tangent at that point, on the $\Delta G°$ axis at − 273° C, should give the value of ΔH°_T at that same temperature. Since neither $\Delta S°$ nor $\Delta H°$ are independent of temperature, it may seem surprising that the free-energy plots should be shown as straight lines and not as curves. There are, however, two reasons which make it possible to do this without much error. Firstly $\Delta S°$ and $\Delta H°$ do not change very greatly with temperature, except at the phase-change points, where abrupt changes in the slopes of the lines correspond to the sharp changes in entropy. Secondly the changes in both $\Delta H°$ and $\Delta S°$, caused by changes in the specific heats of reactants and resultants, affect $\Delta G°$ in such a manner as nearly to counterbalance. This point is illustrated in the case of the three most accurately studied reactions by the following figures :

Temp, °C	From Full Equations $\Delta H°$	From Full Equations $\Delta S°$	From Full Equations $\Delta G°$	From Straight-Line Plot $\Delta H°$	From Straight-Line Plot $\Delta S°$	From Straight-Line Plot $\Delta G°$	Difference in $\Delta G°$ Values
(1) *Reaction :* $2H_2 + O_2 \rightarrow 2H_2O$							
0	−115·5	−21·7	−109·9	−118·1	−26·7	−110·6	+0·7
727	−118·5	−26·4	− 92·1	−118·1	−26·7	− 91·4	−0·7
1727	−120·7	−28·1	− 64·5	−118·1	−26·7	− 64·5	0·0
(2) *Reaction :* $2CO + O_2 \rightarrow 2CO_2$							
0	−135·2	−41·5	−123·6	−135·1	−41·5	−123·6	0·0
727	−135·1	−41·7	− 93·4	−135·1	−41·5	− 93·6	+0·2
1727	−132·7	−40·1	− 52·4	−135·1	−41·5	− 52·2	−0·2
(3) *Reaction :* $2C + O_2 \rightarrow 2CO$							
0	− 52·9	+42·2	− 64·4	− 53·4	+41·8	− 65·0	+0·6
727	− 53·4	+42·5	− 95·9	− 53·4	+41·8	− 95·2	−0·7
1727	− 58·5	+39·0	−136·5	− 53·4	+41·8	−137·1	+0·6

($\Delta H°$ and $\Delta G°$ in kilocalories, $\Delta S°$ in calories per degree)

The above values of $\Delta H°$, $\Delta S°$, and $\Delta G°$ are calculated from the well-established equations, as used, for example, by Thompson,[55] which give a slightly curved plot, and the corresponding values given by the straight-line plots shown in Fig. 1. It is to be noted that although the straight-line plot makes it impossible to obtain *accurate* values of $\Delta S°$ and $\Delta H°$ by means of tangents and intercepts, and gives only mean values for each over the range 0–2000° C, the errors in ΔG°_T caused by the

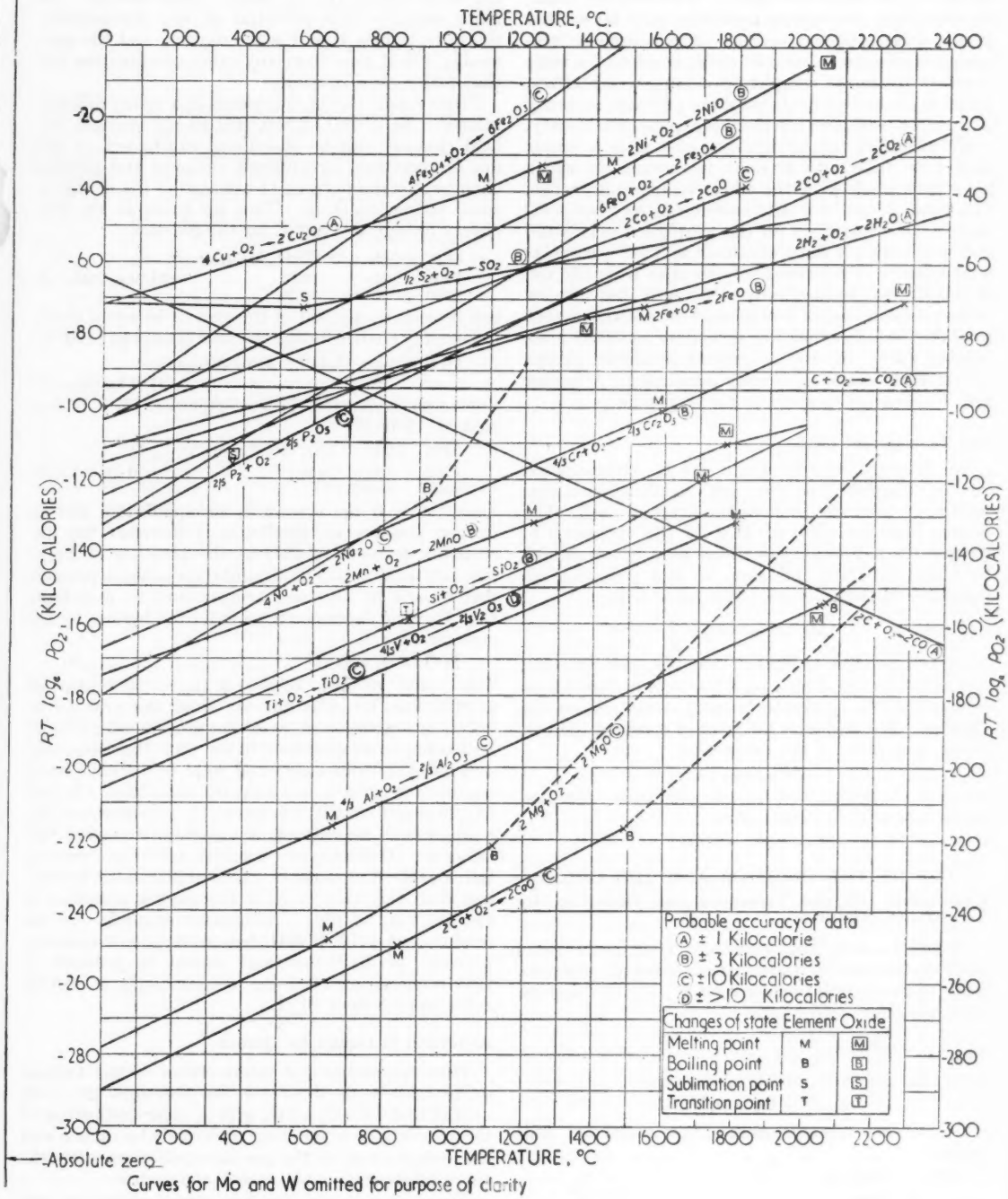
TEMPERATURE, °C.
0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400
-20 -40 -60 -80 -100 -120 -140 -160 -180 -200 -220 -240 -260 -280 -300
RT log$_e$ P_{O_2} (KILOCALORIES)
$4Cu + O_2 \rightarrow 2Cu_2O$ (A)
$4Fe_3O_4 + O_2 \rightarrow 6Fe_2O_3$ (C)
$2Ni + O_2 \rightarrow 2NiO$ (B)
$6FeO + O_2 \rightarrow 2Fe_3O_4$ (C)
$2Co + O_2 \rightarrow 2CoO$ (C)
$2CO + O_2 \rightarrow 2CO_2$ (A)
$2H_2 + O_2 \rightarrow 2H_2O$ (A)
$\frac{1}{2}S_2 + O_2 \rightarrow SO_2$ (B)
$2Fe + O_2 \rightarrow 2FeO$ (B)
$C + O_2 \rightarrow CO_2$ (A)
$\frac{2}{5}P_2 + O_2 \rightarrow \frac{2}{5}P_2O_5$ (C)
$\frac{4}{3}Cr + O_2 \rightarrow \frac{2}{3}Cr_2O_3$ (B)
$4Na + O_2 \rightarrow 2Na_2O$ (C)
$2Mn + O_2 \rightarrow 2MnO$ (B)
$Si + O_2 \rightarrow SiO_2$ (C)
$\frac{4}{5}V + O_2 \rightarrow \frac{2}{5}V_2O_5$ (C)
$Ti + O_2 \rightarrow TiO_2$ (C)
$\frac{4}{3}Al + O_2 \rightarrow \frac{2}{3}Al_2O_3$ (C)
$2Mg + O_2 \rightarrow 2MgO$ (C)
$2Ca + O_2 \rightarrow 2CaO$ (C)
$2C + O_2 \rightarrow 2CO$ (A)
Probable accuracy of data
(A) ± 1 Kilocalorie
(B) ± 3 Kilocalories
(C) ± 10 Kilocalories
(D) ± >10 Kilocalories
Changes of state | Element | Oxide
Melting point | M | (M)
Boiling point | B | (B)
Sublimation point | S | (S)
Transition point | T | (T)
-Absolute zero-
TEMPERATURE, °C
Curves for Mo and W omitted for purpose of clarity

Fig. 1

procedure are very small indeed. Except in the cases of the three reactions quoted, they are much less than the absolute limits of accuracy of the measurements on which the lines are based. Within these limits, therefore, the free-energy equations may be written in the form $\Delta G^\circ = x - Ty$. The complete free-energy equations frequently cited, consist of a large number of almost completely compensating terms, which in general go far beyond the probable accuracy of the data used, and are therefore quite unnecessary.

By means of the straight-line plot it is a simple matter to take into account measurements which have been made over the whole temperature range. The value of ΔG° for any reaction at any temperature, is thus based on all the available information and not only on data obtained at that particular temperature. The error likely to arise from the use of the straight lines is fully recognized, but in view of the probable accuracy of most of the data at present available, it is felt that this procedure gives the most reliable values of ΔG° at present available, except for the three reactions already mentioned. A further note on accuracy is given in the Appendix.

The Transparent Grid

The transparent grid which can be superimposed on the diagram has two additional relationships plotted on the same scale as the diagram itself. The broken lines are plots of ΔG_T for the expansion of oxygen (or any other gas which may be considered as ideal) at 1-atm pressure, to the pressures (p) indicated on the diagram, the relation being:

$$\Delta G_T = -RT\log_e \frac{1}{p}$$

They can be used as lines of equal oxygen pressure, and as will be seen later enable the oxygen dissociation pressure of the oxides to be read directly from the diagram. The full lines are lines of constant CO/CO_2 ratios, and plots of the expression:

$$RT\log_e p_{O_2};$$

where p_{O_2} is determined for any particular ratio and temperature by the equilibrium:

$$2CO + O_2 \rightarrow 2CO_2.$$

USE OF THE DIAGRAM AND THE GRID

Equilibrium Oxygen Pressures and Reduction by CO–CO_2 Mixtures

It will be seen from equation (1) that the value of ΔG°_T, for any of the reactions plotted, gives the value of the equilibrium constant K_T at any temperature, the relationship being:

$$K_T = \text{antilog}_{10}\frac{\Delta G^\circ_T}{4{\cdot}57T} \quad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Since the reactions are all of the type:

$$m_1X_z + O_2 \rightarrow m_2M_xO_y$$

it follows that in the presence of pure metal and oxide phases:

$$\frac{K_T = (M_xO_y)^{m_2}}{(X_z)^{m_1}p_{O_2}} = \frac{1}{p_{O_2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

The values of p_{O_2}, in equilibrium with pure phases of any metal and its oxide, are thus directly calculable for all temperatures in the range plotted. They are the equilibrium oxygen dissociation pressures of the oxide in question. It is frequently helpful to consider ΔG°_T, which under these conditions equals $-RT\log_e(1/p_{O_2})$ or $(RT\log_e p_{O_2})$, as *the oxygen potential* of the oxide–metal system under consideration. The more negative this potential at any temperature, the more tightly bound is the oxygen, and the more readily will it pass from any other combination into that under consideration.

These results can be considered in a rather different manner. As is well known, free-energy changes, like heat changes, can be added and subtracted, at any one temperature, for different chemical and physical changes, for the purpose of calculating the change in some further reaction. Thus for example the free-energy change at 1190° C for the reaction:

$$\underset{\text{Pure solid}}{2Fe} + \underset{\text{1-atm pressure}}{O_2} \rightarrow \underset{\text{solid}}{2FeO} \quad \Delta G^\circ_{1190^\circ C} = -81{\cdot}0 \text{ kg.cal.} \ldots(6)$$

can be seen by the aid of the grid to be equal to the free-energy change for the physical change at 1190° C:

$$O_2\,(1 \text{ atm}) \rightarrow O_2\,(10^{-12} \text{ atm}) \quad \Delta G_{1190^\circ C} = -81{\cdot}0 \text{ kg.cal.} \ldots(7)$$

Subtracting equation (7) from equation (6) it is seen that at 1190° C:

$$\underset{\text{Pure solid}}{2FeO} \rightarrow \underset{\text{pure solid}}{2Fe} + \underset{\text{gas}}{O_2\,(10^{-12} \text{ atm})} \quad \Delta G_{1190^\circ C} = 0 \text{ kg.cal.} \ldots(8)$$

Since $\Delta G = 0$ the system is in equilibrium and an oxygen pressure of 10^{-12} atm is therefore the dissociation pressure of FeO in the presence of Fe at this temperature. This equilibrium oxygen pressure corresponds at any one temperature to a definite CO/CO_2 ratio determined, as indicated before, by the equilibrium:

$$2CO + O_2 \rightarrow 2CO_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots(9)$$

The value of the ratio for $p_{O_2} = 10^{-12}$ atm at 1190° C can be seen directly from the grid to be 2·7/1, interpolation between the grid lines for 1/1 and 10/1 being on a *logarithmic* basis. It is thus seen that at 1190° C ferrous oxide and solid iron would be in equilibrium with a gas mixture containing CO and CO_2 in a ratio of 2·7/1 respectively; furthermore the oxide would be reduced if the ratio exceeded this value (*i.e.*, if the oxygen potential of the gas were to fall) and the iron would be oxidized if the ratio became less than this value (*i.e.*, if the oxygen potential of the gas were to rise). As another example one can read that at 1470° C, SiO_2 has an oxygen dissociation pressure of 10^{-14} atm and should be reduced at that temperature by a gas mixture with a CO/CO_2 ratio greater than $10^4/1$.

Reduction of Oxides by Carbon

The separations and intersections of the various oxide lines with those for the reactions $2C + O_2 \rightarrow 2CO$ and $C + O_2 \rightarrow CO_2$ give a clear indication of the possibilities of reducing each oxide by carbon and the composition of the gas in equilibrium with the three substances, oxide, metal, and carbon.

Thus, for example, the free-energy change at any temperature for the reaction $2MnO + 2C \rightarrow 2Mn + 2CO$ can be obtained from the diagram by subtraction of the changes for the two separate reactions as follows:

$$2Mn + O_2 \rightarrow 2MnO \quad \ldots\ldots(10)$$
$$2C + O_2 \rightarrow 2CO \quad \ldots\ldots(11)$$
$$2MnO + 2C \rightarrow 2Mn + 2CO \quad \ldots\ldots(12)$$

At 1410° C, where the lines for equation (10) and equation (11) intersect, $\Delta G^\circ_{1410^\circ C}$ for equation (12) is equal to zero, so that the three substances should be in equilibrium with carbon monoxide in its standard state of 1-atm pressure. At this temperature, therefore, reduction should take place provided that the carbon monoxide pressure is kept below 1 atm. Alternatively it should take place at a carbon monoxide pressure of 1 atm at temperatures above 1410° C. The pressure of carbon dioxide under these conditions is controlled by the simultaneous equilibrium : $2MnO + C \rightarrow 2Mn + CO_2$. For this reaction $\Delta G^\circ_{1410^\circ C}$ can be obtained from the values for the reactions as follows :

$$2Mn + O_2 \rightarrow 2MnO \qquad \Delta G^\circ_{1410^\circ C} = -122{\cdot}0 \text{ kg.cal.} \ldots(13)$$
$$C + O_2 \rightarrow CO_2 \qquad \Delta G^\circ_{1410^\circ C} = -94{\cdot}0 \text{ kg.cal} \ldots(14)$$
$$2MnO + C \rightarrow 2Mn + CO_2 \qquad \Delta G^\circ_{1410^\circ C} = -28{\cdot}0 \text{ kg.cal.} \ldots(15)$$

On the reasoning in the preceding section, — 28·0 kg. cal. is thus the value of $\Delta G_{1410^\circ C}$ for the expansion of carbon dioxide gas at 1-atm pressure to the equilibrium pressure. Therefore :

$$CO_2 \text{ (1 atm)} \rightarrow CO_2 \text{ (equilibrium pressure)} \qquad \Delta G_{1410^\circ C} = -28{\cdot}0 \text{ kg.cal.}$$

and the value of p_{CO_2} at equilibrium is given by the equation :

$$p_{CO_2} = -\text{antilog}\frac{28{,}000}{4{\cdot}57 \times 1683} = \text{antilog} -3{\cdot}64 = 2{\cdot}3 \times 10^{-4} \text{ atm}$$

This value can again be determined directly from the grid by reading the value of the CO/CO_2 ratio at the intersection. By interpolating between the grid lines $10^3/1$ and $10^4/1$ on a logarithmic scale, the value of the ratio is seen to be $4{\cdot}3 \times 10^3/1$, giving $p_{CO_2} = 2{\cdot}3 \times 10^{-4}$ atm, since $p_{CO} = 1$ atm.

To determine, for example, the CO pressure in equilibrium with these substances at 1000° C, it is necessary to find $\Delta G^\circ_{1000^\circ C}$ by subtraction for the following change :

$$2MnO + 2C \rightarrow 2Mn + 2CO \qquad \Delta G^\circ_{1000^\circ C} = +140{\cdot}0 - 160{\cdot}0 = +34 \text{ kg.cal.}$$

and then to calculate p_{CO} as follows :

$$K_p = \frac{p^2_{CO} \times (Mn)^2}{(MnO)^2 \times (C)^2} = \text{antilog} -\frac{\Delta G^\circ_{1000^\circ C}}{2{\cdot}303RT} = \text{antilog}\frac{-34{,}000}{4{\cdot}57 \times 1273} = 1{\cdot}44 \times 10^{-6}$$

Since, in this case also, all the non-gaseous components are present as pure solid phases and their concentrations are unity by definition, it follows that :

$$p_{CO} = 1{\cdot}44 \times 10^{-6} = 1{\cdot}2 \times 10^{-3} \text{ atm}$$

Here again the transparent grid can be used, since the oxygen isobars give in fact the values of ΔG_T, for *one* gram molecule of any ideal gas at all temperatures, for pressure changes of multiples from one to 10^{-150}. In this case it is required to find the pressure p_{CO} for which the value of ΔG_T for *two* gram molecules of gas expanding from one atmosphere to p_{CO} is equal to — 34·0 kg.cal. (*i.e.*, that for which ΔG_T for *one* gram molecule is equal to — 17·0 kg.cal.) It will be seen that this also gives $p_{CO} = 1{\cdot}2 \times 10^{-3}$. The CO_2 pressure in equilibrium with the system can be determined by reading the CO/CO_2 ratio directly from the grid for the point — 139·5 kg.cal., 1000° C, and dividing into the equilibrium CO pressure :

$$p_{CO_2} = \frac{p_{CO}}{p_{CO}/p_{CO_2}} = 1{\cdot}2 \times 10^{-3}/6{\cdot}8 \times 10^4 = 1{\cdot}76 \times 10^{-8}$$

It may alternatively be required to determine for certain instances the temperature at which MnO could be reduced by carbon in the presence of 0·1 atm of carbon monoxide. In this case the temperature must be found at which half the difference in ΔG°_T between the Mn–MnO and the C–CO lines (since two molecules of CO are involved in equation (8)) is equal to the value of ΔG°_T for a ten-times change in pressure (*i.e.*, $2{\cdot}303RT\log 10 = 4{\cdot}575T$). This again may be done with the aid of the oxygen isobars on the grid, for the 10^{-1} line is a plot of $4{\cdot}575T$ against T ; it will be seen that the temperature is 1240° C.

LIMITATIONS

It is important to stress that the diagram gives no indication of reaction rates, since these are dependent upon kinetic and not thermodynamic factors. It will be seen for example that cuprous oxide (Cu_2O) can theoretically be reduced by carbon, at 1-atm pressure of carbon monoxide, at 100° C. At this temperature, however, the rate of the reaction is so slow that it can be considered as not taking place. It is, however, a fact that at the high temperatures of interest in extractive metallurgy, most reactions proceed at reasonable rates. It is therefore generally true that when there is a significant decrease in free energy in a reaction at high temperature it will, in fact, proceed. When there is an increase in free energy it can definitely be stated that no reaction will occur whatever the temperature.

In the definitions at the beginning of this paper the equilibrium constant was expressed in terms of partial pressures for gases and molar fractions (equal to unity) for the pure solids and liquids. This constant should, of course, strictly be expressed in terms of *activities*. For a gas this activity normally approximates closely to its partial pressure. For substances in solution in solids and liquids, however, the activities are seldom equal to the molar fractions, and large errors will arise if equilibrium constants are calculated from these curves and used with molar fractions instead of activities. The activity aspect will be dealt with in detail in a subsequent paper when iron and slag solutions are considered.

GENERAL CONSIDERATIONS

Once the method of using the diagram is understood, it will be recognized that it provides both a ready means of sorting out complicated equilibria, and an easily remembered picture co-ordinating a vast number of experimental facts. The visual framework provided by the curves enables any reaction or process to be appreciated in relation to an adequate

chemical background and suggests at once in what direction one should look in order to effect improvements and to overcome obstacles of a thermodynamic nature.

A further advantage of this pictorial method of collating data is that it enables one to spot improbable results, and also arithmetical errors in the complex heat-content and free-energy equations which are to be found in many compilations of thermochemical data. There are for instance two curves to chose from for the reaction ($\frac{4}{3}V + O_2 \rightarrow \frac{2}{3}V_2O_3$). One is based on an estimated value for the specific heat of V_2O_3 and the other on subsequently measured values. The former gives a line with a small slope which cuts right across the lines for TiO_2 and Al_2O_3, whereas the latter gives a reasonable slope (*i.e.*, entropy change) which fits well into the general pattern.

The general pattern is of considerable interest. The similarity in the upward slopes of the solid-metal/oxide lines is striking and is in marked contrast to the horizontal line for ($C + O_2 \rightarrow CO_2$) and to the downward sloping line ($2C + O_2 \rightarrow 2CO$). These similar upward slopes are due to similar entropy changes for the formation of the metal oxides. These are to be expected, since the major contribution to the entropy change in all these cases arises from the conversion of one gram molecule of oxygen gas at 1-atm pressure into solid oxide, consisting in general of closely packed oxygen ions with metal ions in between. The direction is upward because there is a large decrease in entropy on binding and restricting the oxygen in this way. Since an increase in temperature favours a less restricted state for the components of any system, it is also to be expected that rising temperature should favour dissociation of the oxides by making available the necessary energy to overcome the binding forces. In the case of the CO_2 reaction there is almost zero entropy change, and in the case of the CO reaction there is a marked decrease. This again is to be expected since gaseous (CO_2) and particularly gaseous (2CO) are far less restricted states than the solid or liquid metallic oxides. As a result these oxides are not decomposed with rising temperatures nearly so readily as are the metal oxides, and it is this fact that makes it possible to reduce all metallic oxides by carbon at sufficiently high temperatures.

It is to be noted, however, that even these gaseous oxides become less stable on heating, because, as the diagram shows, the partial pressure of oxygen, in equilibrium with carbon and gaseous oxide at 1-atm pressure, increases with temperature. The only reactions which are favoured in an absolute sense by increasing temperatures are those which are endothermic. All the reactions shown on the diagram are exothermic in the direction indicated, so that the effect of an increase in entropy, as opposed to a decrease, is to mitigate to some extent the effect of temperature in causing decomposition.

APPENDIX

ACCURACY OF THE DIAGRAM

The accuracy of the information presented in the diagram is difficult to estimate, since the authors of the relevant papers so often give no indication of the accuracy of their determinations. Each curve has therefore been assigned, as well as possible, to one of the four classes listed below and indicated in the diagram, depending on the estimated accuracy of *all* the data used in the calculation. It is sometimes the case, for instance, that a very precise measurement of the specific heat of a substance is associated with a class-*D* curve, since the heat of the reaction is not accurately known. It should be noted, however, that this classification can only be approximate, since entropy errors at low temperatures will cause errors in ΔG° which increase markedly as the temperature rises.

Category	Accuracy, kg.cal.
A	± 1
B	± 3
C	±10
D	± > 10

In cases in which it is desired to determine the value of ΔG° for a reaction by addition or subtraction of the values given in the diagram, the accuracy may be considerably greater than that indicated by compounding the absolute accuracy gradings. This is because in a number of cases, the position of one line may have been determined very accurately with reference to another, although the absolute position of each separately may have been only roughly established. In such cases, therefore, before the results given here are used for accurate calculations, it is advisable to refer to the following detailed data and, if necessary, to the original papers. A similar situation arises where a reaction has been very accurately studied over a small temperature range, and only indifferently over the remainder.

All the ΔG° equations are given in calories.

DATA USED

Aluminium ($\frac{4}{3}Al + O_2 \rightarrow \frac{2}{3}Al_2O_3$). Accuracy *C*

$$\Delta G^\circ_{298\text{–}930^\circ K} = -256{,}600 + 43{\cdot}3T$$
$$\Delta G^\circ_{930\text{–}2318^\circ K} = -257{,}500 + 44{\cdot}3T$$
$$\Delta G^\circ_{2318\text{–}2330^\circ K} = -240{,}200 + 36{\cdot}8T$$
$$\Delta G^\circ_{2330\text{–}2500^\circ K} = -321{,}600 + 71{\cdot}8T$$

Up to the melting point of Al_2O_3 the figures given by Thompson[55] were used. His values, which were checked, are a weighted mean of calculations from thermal data, and from equilibrium results for a number of reactions. The curve above the melting point of Al_2O_3 was obtained by extrapolation after introducing a change of slope corresponding to the entropy of fusion as given by Kelley.[32] Chipman's equation,[7] which is based on unspecified data, gives a value of ΔG° 5 kg.cal. more negative than that given here at 1800° C.

The main errors in the calculations from thermal data arise from the uncertainty of at least 8 kg.cal. in the value of $\Delta H^\circ_{25^\circ C}$. The results from them do, however, check reasonably with the calculations made by Treadwell and Terebesi[58] from a number of equilibrium results, including those obtained by Fischer and Gewehr[19] for the reaction $2AlCl_3$ (gas) + $3H_2O$ (gas) = Al_2O_3 (solid) + 6HCl (gas). It may be added that the most recent determination of the high-temperature specific heat of Al_2O_3 by Shomate and Naylor[51] agrees with values used by Thompson,

within much narrower accuracy limits than the 8 kg.cal. quoted for $\Delta H^{\circ}_{25^{\circ}C}$, and does not, therefore, necessitate a fresh calculation.

Calcium ($2Ca + O_2 \rightarrow 2CaO$). Accuracy *C*

$$\Delta G^{\circ}_{298\text{–}1124^{\circ}K} = -302{,}640 + 47{\cdot}32T$$
$$\Delta G^{\circ}_{1124\text{–}1760^{\circ}K} = -307{,}100 + 51{\cdot}28T$$
$$\Delta G^{\circ}_{1760\text{–}2500^{\circ}K} = -380{,}250 + 93{\cdot}24T$$

The thermal data for metallic calcium unfortunately extend only to 600° C. The procedure adopted, therefore, was to obtain a curve for ΔG° from 25° to 600° C using the figure quoted by Bichowsky and Rossini[3] for the heat of formation of CaO at 25° C and the data compiled by Kelley for the high-temperature specific heats[30] and for the entropies at 25° C.[34] This curve was then extrapolated to the melting point of calcium where a change of slope was introduced based on Kelley's figure for the entropy of melting.[32] A similar procedure was adopted at the boiling point, the entropy of vaporization again being taken from Kelley.[31] The results agree with Thompson's calculations[55] up to the boiling point of calcium, but the latter appear to be in error above that temperature.

Carbon ($C + O_2 \rightarrow CO_2$). Accuracy *A*

$$\Delta G^{\circ}_{298\text{–}2500^{\circ}K} = -94{,}200 - 0{\cdot}20T$$

($2C + O_2 \rightarrow 2CO$). Accuracy *A*

$$\Delta G^{\circ}_{298\text{–}2500^{\circ}K} = -53{,}400 - 41{\cdot}90T$$

($2CO + O_2 \rightarrow 2CO_2$). Accuracy *A*

$$\Delta G^{\circ}_{298\text{–}2500^{\circ}K} = -135{,}100 + 41{\cdot}50T$$

The calculations of Thompson[55] were used throughout as the best available. They agree with those made by Chipman[7] and are all mutually concordant.

Chromium ($\frac{4}{3}Cr + O_2 \rightarrow \frac{2}{3}Cr_2O_3$). Accuracy *B*

$$\Delta G^{\circ}_{298\text{–}1868^{\circ}K} = -178{,}500 + 41{\cdot}40T$$
$$\Delta G^{\circ}_{1868\text{–}2500^{\circ}K} = -183{,}740 + 44{\cdot}21T$$

This curve was constructed largely on data which have been given by Chen and Chipman,[6] who quote the calculation of Maier.[36] These are based on a value of −268,900 cal, determined by Roth and Wolf[46] for the heat of formation of Cr_2O_3 at 25° C, Kelley's entropy values at 25° C,[34] Kelley's high-temperature specific heats for chromium and oxygen, and Maier's *estimated* high-temperature specific-heat equation for Cr_2O_3.[30] Chen and Chipman have compared the results of these calculations with the equilibrium measurements of Wartenberg and Aoyama,[61] Grübe and Flad,[24] and Granat.[23] These are all sufficiently concordant to support the use of the estimated specific-heat equations. The curve was extended above the melting point of chromium by means of Kelley's figure for its entropy of fusion.[32] Although the heat of formation of Cr_2O_3 is in doubt by 3–5 kg.cal., it is thought that the concordance of the thermal data with the equilibrium measurements warrants the allocation of this curve to category *B*.

Cobalt ($2Co + O_2 \rightarrow 2CoO$). Accuracy *C*

$$\Delta G^{\circ}_{298\text{–}1763^{\circ}K} = -111{,}800 + 34{\cdot}35T$$
$$\Delta G^{\circ}_{1763\text{–}2200^{\circ}K} = -121{,}060 + 39{\cdot}20T$$

The values used here were those calculated by Thompson[55] from the gas–metal equilibrium studies made by Emmett and Shultz,[17] Watanabe,[62] and Kapustinsky and Gofman.[28] Thompson used an estimated constant value of 10·2 for the specific heat of CoO, Kelley's[30] figures for the specific heats of cobalt, and Johnston and Walker's[27] for oxygen. Chipman's free-energy equation[7] gives more negative values than those given here, the difference being 1½ kg.cal. at the melting point of cobalt (1490° C). Although the three sets of equilibrium data give results which agree within a few kilocalories, it is considered that the use of a constant value for the specific heat of CoO will result in larger inaccuracies at the highest temperatures. The curve is therefore graded as category *C*.

Copper ($4Cu + O_2 \rightarrow 2Cu_2O$). Accuracy *A*

$$\Delta G^{\circ}_{298\text{–}1357^{\circ}K} = -79{,}700 + 30{\cdot}12T$$
$$\Delta G^{\circ}_{1357\text{–}1509^{\circ}K} = -92{,}140 + 39{\cdot}28T$$
$$\Delta G^{\circ}_{1509\text{–}1573^{\circ}K} = -65{,}260 + 21{\cdot}44T$$

The values taken up to the melting point of copper are those calculated by Thompson.[55] He used the e.m.f. measurements of oxidation reduction cells made by Maier,[38] Ishikawa and Kimura,[25] and Allmand,[1] and also Maier's equilibrium studies[37] of the CO/CO_2 equilibrium over Cu/Cu_2O mixtures at higher temperatures. According to Thompson, these lines of investigation agree well to give $\Delta G^{\circ}_{25^{\circ}C} = -35{\cdot}3$ kg.cal. for the formation of Cu_2O. It is on this figure and on the following specific-heat data that his equation is based: Copper, Kelley[30]; Cu_2O, Magnus, quoted by Randall, Nielson, and West[43]; oxygen, Johnston and Walker.[27] This curve was extended above the melting points of copper and of Cu_2O by means of Kelley's values for their latent heats of fusion.[32]

Hydrogen ($2H_2 + O_2 \rightarrow 2H_2O$). Accuracy *A*

$$\Delta G^{\circ}_{373\text{–}2500^{\circ}K} = -118{,}000 + 26{\cdot}75T$$

The values used are those calculated by Thompson[55] on the basis of $\Delta G^{\circ}_{25^{\circ}C}$ and $\Delta H^{\circ}_{25^{\circ}C}$ measured by Rossini,[45] and the specific heats of H_2O by Gordon,[22] oxygen by Johnston and Walker,[27] and hydrogen by Davis and Johnston.[15] These also agree with the equation given by Chipman.[7] The curve was extended below 100° C by means of the value of the latent heat of vaporization of water given by Kelley.[31]

Iron ($4Fe_3O_4 + O_2 \rightarrow 6Fe_2O_3$). Accuracy *C*

$$\Delta G^{\circ}_{298\text{–}1460^{\circ}K} = -119{,}250 + 67{\cdot}25T$$

Simon and Schmidt[53] and Ruer and Nakamoto[47] have measured the equilibrium oxygen pressure exerted when Fe_2O_3 is heated, but the results are not very concordant. The procedure adopted was therefore to fix the low-temperature end of the curve by calculating ΔH°_0 from the value of $\Delta H^{\circ}_{25^{\circ}C}$ given by Bichowsky and Rossini,[3] and the necessary low-temperature heat data from Kelley,[34] and then to draw the best line through this point and the values of ΔG° calculated from the higher temperature measurements.

$6FeO$ (wustite) $+ O_2 \rightarrow 2Fe_3O_4$.* Accuracy *B*

$$\Delta G^{\circ}_{298\text{–}1642^{\circ}K} = -149{,}250 + 59{\cdot}80T$$

* On account of the dependence of the composition of wustite on oxygen pressure and temperature, this equation is stoichiometric with respect to oxygen only.

Darken and Gurry[14] have studied the CO/CO_2 ratios in equilibrium with FeO/Fe_3O_4 mixtures from 1100° to 1400° C. Cirilli[10] has investigated the same system from 900° to 1100° C. The two sets of data agree to within 1 kg.cal. The curve shown is the best line drawn through these results and the point on the curve ($2Fe + O_2 \rightarrow 2FeO$) at which $Fe/FeO/Fe_3O_4$ are mutually stable, *i.e.*, at 560° C.[14] Although the two sets of equilibrium data agree to within 1 kg.cal. in the neighbourhood of 1000° C, extrapolation of the data to lower temperatures makes the overall probable error somewhat greater than this.

$2Fe + O_2 \rightarrow 2FeO$ (wustite).* Accuracy *B*

$$\Delta G^\circ_{298\text{–}1642^\circ\,K} = -124{,}100 + 29{\cdot}90T$$
$$\Delta G^\circ_{1642\text{–}1808^\circ\,K} = -103{,}950 + 17{\cdot}71T$$
$$\Delta G^\circ_{1808\text{–}2000^\circ\,K} = -111{,}250 + 21{\cdot}67T$$

Chipman and Marshall[9] have studied the equilibrium of $H_2/H_2O/Fe/FeO$ in the solid and liquid FeO range. Emmett and Schultz[18] have investigated the same equilibrium in the solid FeO range, and Darken and Gurry[14] and Cirilli[10] have measured the corresponding equilibrium with CO and CO_2. All these results were plotted and the best straight lines were drawn through them, with a break at the melting point of FeO. The change of slope agrees well with the entropy of fusion deduced for FeO by Chipman and Marshall by a similar method. All the points lie within $\pm$ 1 kg.cal. of the straight lines, but the error may be rather greater below the lowest experimental point at 500° C. The value of $\Delta G^\circ_{25^\circ C}$ calculated from Bichowsky and Rossini's[3] $\Delta H^\circ_{25^\circ C}$ and Kelley's[34] values for all the entropies lie about 1·25 kg.cal. below the extrapolated line. The various solid–solid transitions in iron were neglected since they can affect the ΔG° values only within the present limits of error.

The results of Marshall and Chipman[39] were used for the liquid-iron range. These depend on their own measurements of CO/CO_2 ratios in equilibrium with oxygen dissolved in liquid iron, together with the data for the solubility of oxygen (from FeO) in liquid iron of Chipman and Fetters.[8] The ΔG° values lie on a curve which deviates markedly from a straight line. In view, however, of the concordance of the results below the melting point of iron and the accuracy to which the entropy of fusion of the metal is known, it was decided to extrapolate linearly from the lower temperatures, after introduction of the correct change of slope. The resulting line passes through the curve of Chipman and Marshall's ΔG° values, the greatest deviation being 1·2 kg.cal. It is suggested that the straight line may well be more reliable than Chipman and Marshall's results, in view of the many possible sources of error in the direct methods of determination employed by them.

Magnesium ($2Mg + O_2 \rightarrow 2MgO$). Accuracy *C*

$$\Delta G^\circ_{298\text{–}923^\circ\,K} = -290{,}400 + 46{\cdot}17T$$
$$\Delta G^\circ_{923\text{–}1380^\circ\,K} = -298{,}400 + 55{\cdot}4T$$
$$\Delta G^\circ_{1380\text{–}2000^\circ\,K} = -359{,}754 + 102{\cdot}6T$$

Thompson's[55] equation was used. He calculated ΔG° for this reaction from the values of $\Delta H^\circ_{25^\circ C}$ given by Bichowsky and Rossini,[3] the entropies at 25° C quoted by Kelley,[34] the high-temperature specific heat of oxygen by Johnston and Walker,[27] and other high-temperature specific heats by Kelley.[30] This gives a ΔG° curve, which he has shown to agree well with values calculated indirectly both from the equilibrium measurements of chlorine and oxygen over solid MgO and $MgCl_2$ mixtures made by Treadwell and Cohen,[60] Sano,[48] and Moldenhauer,[40] and also from the e.m.f. measurements of the cell Mg (liquid) $MgCl_2$ (liquid)$|Cl_2|$C made by Treadwell, Amman, and Zürrer.[59] Chipman's[7] equation gives a value for ΔG° of 1 kg.cal. more negative at the boiling point of magnesium. Some uncertainty is caused, however, by the very different values which can be calculated for ΔG° from the e.m.f. measurements of the cell Mg (liquid)$|Mg + MgF_2$ (solid)$|O_2$, made by Treadwell, Amman, and Zürrer[59] and by Thompson and Kaye.[56] The curve was extrapolated into the gaseous-magnesium range by means of Kelley's value for its latent heat of vaporization.[31]

Manganese ($2Mn + O_2 \rightarrow 2MnO$). Accuracy *B*

$$\Delta G^\circ_{298\text{–}1500^\circ\,K} = -183{,}900 + 34{\cdot}63T$$
$$\Delta G^\circ_{1500\text{–}2051^\circ\,K} = -190{,}800 + 39{\cdot}25T$$
$$\Delta G^\circ_{2051\text{–}2200^\circ\,K} = -162{,}200 + 25{\cdot}25T$$

Southard and Shomate[54] have measured the heat of formation of MnO and the heat capacity of manganese and MnO up to 1227° C. In their paper they have collated their own results with those of other workers, and have provided the best set of thermal data up to that temperature. They have calculated ΔG° for the reaction from their own measurements, for Kelley's[34] values for the 25° C entropies of all the substances involved, and for Johnston and Walker's[27] values for the high-temperature specific heat of oxygen. These ΔG° values were plotted from 25° to 1227° C and were found to deviate from a straight line by less than ½ kg.cal. The free-energy curve was extrapolated to higher temperatures using Kelley's[32] value for the latent heat of fusion of manganese, and Chipman's[7] value for MnO, which is based on unspecified data.

Molybdenum ($Mo + O_2 \rightarrow MoO_2$). Accuracy *C*

$$\Delta G^\circ_{298\text{–}1200^\circ\,K} = -133{,}600 + 43{\cdot}07T$$

Use was made of measurements of Tonosaki[57] for H_2/H_2O ratios in equilibrium with Mo/MoO_2 mixtures from 645° to 823° C. The best line was drawn through these points and that of $\Delta G^\circ_{25^\circ C}$ calculated from Bichowsky and Rossini's[3] value of $\Delta H^\circ_{25^\circ C}$ and Kelley's entropy data.[34]

Nickel ($2Ni + O_2 \rightarrow 2NiO$). Accuracy *B*

$$\Delta G^\circ_{298\text{–}1725^\circ\,K} = -116{,}900 + 47{\cdot}10T$$
$$\Delta G^\circ_{1725\text{–}2200^\circ\,K} = -125{,}300 + 51{\cdot}96T$$

Use was made of Thompson's[55] calculations which are based on the CO/CO_2 and H_2/H_2O equilibrium measurements with Ni/NiO by Kapustinsky and Silberman[29] and by Bogatskii.[4] Thompson has averaged these results with those calculated from thermal data, using Bichowsky and Rossini's[3] value for the heat of formation of NiO, Seltz, Dewitt, and

* On account of the dependence of the composition of wustite on oxygen pressure and temperature, this equation is stoichiometric with respect to oxygen only.

McDonald's[49] figures for the entropy of NiO at 25° C and for the specific heat of NiO, Kelley's[30] data for the specific heat of nickel, and Johnston and Walker's[27] specific-heat values for oxygen. The curve from Thompson's figures agrees with the equation of Chipman,[7] at the melting point of nickel to within ½ kg.cal. Although the equilibrium measurements referred to above agree well, the absolute accuracy of the data may not be better than category *B*, since other equilibrium measurements which have been reported are not equally concordant.

Phosphorus $(\frac{2}{5}P_2 + O_2 \rightarrow \frac{2}{5}P_2O_5)$. Accuracy *C*

$$\Delta G^\circ_{298\text{–}631^\circ\,K} = -151{,}600 + 55{\cdot}40T$$
$$\Delta G^\circ_{631\text{–}1400^\circ\,K} = -148{,}000 + 49{\cdot}37T$$

Although the available data are not sufficient to make a rigorous calculation, it was thought that an approximation should be attempted because of the great importance of phosphorus in iron and steel making. The following thermal data were used: Heat of formation at 25° C from Bichowsky and Rossini[3]; heat of sublimation of phosphorus and of P_2O_5, entropy of oxygen at 25° C, and heat capacity of P_2O_5 from Kelley[30, 34]; entropy and heat capacity of phosphorus from Godnev and Sverdlin[21]; and specific heat of oxygen from Johnston and Walker.[27] Unfortunately no figure is available for the entropy at 25° C of P_2O_5. An estimate for this was made from the entropies at 25° C of the periodic group As_2O_5 (25·2); V_2O_5 (31·3); P_2O_5 (—); N_2O_5 (solid) (36·6), and a value for P_2O_5 of 33·5 was adopted.[34] It seems likely that this estimate is accurate to within 2 units and may thus cause an error in the value of ΔG° rising to 4 kg.cal. at 1600° C. The probable errors in all the other data are likely to be of the same order.

Silicon $(Si + O_2 \rightarrow SiO_2)$. Accuracy *B*

$$\Delta G^\circ_{298\text{–}1700^\circ\,K} = -208{,}300 + 43{\cdot}30T$$
$$\Delta G^\circ_{1700\text{–}1973^\circ\,K} = -217{,}570 + 48{\cdot}79T$$
$$\Delta G^\circ_{1973\text{–}2200^\circ\,K} = -215{,}470 + 47{\cdot}73T$$

The curve for this reaction was calculated from the following thermal data: Heat of formation at 20° C from Roth and Troitzsch[45(c)]*; entropies at 25° C from Kelley[34]; specific heat of silicon from Kelley[30]; specific heat of oxygen from Johnston and Walker[27]; and specific heat of SiO_2 from Mosesman and Pitzer.[42]

Sodium $(4Na + O_2 \rightarrow 2Na_2O)$. Accuracy *C*

$$\Delta G^\circ_{293\text{–}371^\circ\,K} = -194{,}500 + 55{\cdot}20T$$
$$\Delta G^\circ_{371\text{–}1150^\circ\,K} = -197{,}000 + 62{\cdot}0T$$
$$\Delta G^\circ_{1150\text{–}1500^\circ\,K} = -289{,}500 + 139{\cdot}9T$$

Use was made of Thompson's calculations,[55] which are based on measurements by Barta[2] on the e.m.f.'s of the cell Na (liquid)|NaOH (liquid)|Na_2O (satd.)|O_2 from 300° to 650° C. Thompson has used Barta's estimated specific-heat equation for Na_2O, the specific heat of sodium by Kelley,[30] and the specific heat of oxygen by Johnston and Walker.[27] The values for the solid-sodium part of the ΔG° curve appear when plotted from Thompson's equation to give a slight change of slope in the opposite direction from that to be expected from the melting of metal. The curve has accordingly been graphically recalculated. It is tentatively graded as category *C* although it has a suspiciously high slope.

Sulphur $(\frac{1}{2}S_2 + O_2 \rightarrow SO_2)$. Accuracy *B*

$$\Delta G^\circ_{298\text{–}830^\circ\,K} = -70{,}845 - 1{\cdot}71T$$
$$\Delta G^\circ_{830\text{–}2200^\circ\,K} = -86{,}525 + 17{\cdot}25T$$

Kelley's[33] calculations were used to plot ΔG° for this reaction. These are based on spectroscopically determined values of the free energies of sulphur gas by Montgomery and Kassel,[41] Cross,[12] and Godnev and Sverdlin[20]; of sulphur dioxide gas by Cross,[13] and of oxygen gas by Johnston and Walker.[27] For the purpose of simplicity the standard states of sulphur adopted for the curve were solid rhombic below 557° C and sulphur gas above this point. The results can be applied to the other forms of sulphur by use of Kelley's equations.[33]

Titanium $(Ti + O_2 \rightarrow TiO_2)$. Accuracy *C*

$$\Delta G^\circ_{298\text{–}2080^\circ\,K} = -217{,}500 + 41{\cdot}4T$$

The values taken for ΔG° are those calculated by Thompson,[55] using $\Delta H^\circ_{25^\circ C}$ from Bichowsky and Rossini,[3] the specific heats of titanium and TiO_2 from Kelley,[30] the specific heat of oxygen from Johnston and Walker,[27] and the entropies at 25° C from Kelley.[34] These data extend only to 440° C. Chipman[7] gives an equation for this reaction at high temperatures based on unspecified data, but classified by him as "good measurements of indirect data." The value given by this equation at 1600° C agrees with that obtained by extrapolating Thompson's low-temperature values, and this line has therefore been taken to cover the full temperature range. In view of the unknown source of the data used by Chipman, the accuracy is graded as *C*.

Tungsten $(W + O_2 \rightarrow WO_2)$. Accuracy *C*

$$\Delta G^\circ_{298\text{–}1400^\circ\,K} = -131{,}250 + 38{\cdot}05T$$

The H_2/H_2O ratios in equilibrium with tungsten and WO_2 have been measured by Chaudron,[5] Wohler and Gunther,[63] and Reinders and Vervloet.[44] Chaudron's results have been collated by Liempt,[35] and Shibata[50] measured the CO/CO_2 ratios in equilibrium with this system. A plot was made of ΔG° for $(W + O_2 \rightarrow WO_2)$ calculated from the empirical equations given by all these workers and the appropriate H_2/H_2O and CO/CO_2 data, and the best line was drawn through these results. The greatest deviation from this line at any point was — 2½ kg.cal., but since the slopes of the results of the different investigations are significantly different, category *C* accuracy is allocated over the range 25–1200° C.

Vanadium $(\frac{4}{3}V + O_2 \rightarrow \frac{2}{3}V_2O_3)$. Accuracy *D*

$$\Delta G^\circ_{298\text{–}1995^\circ\,K} = -206{,}800 + 38{\cdot}9T$$

ΔG° was calculated from the following thermal data: Entropies at 25° C from Kelley[34]; high-temperature specific heats of oxygen from Johnston and

* Roth and Troitzsch's value, which is preferred to that given by Bichowsky and Rossini,[3] is based on measurements of the heat of formation of α-cristobalite by Roth and Becker[45(a)] and the heat of transition of α-cristobalite to α-quartz by Roth and Troitzsch.[45(b)]

Walker,[27] of vanadium from Jaeger and Veenstra,[26] and of V_2O_3 from Cook.[11] $\Delta H^{\circ}_{25^{\circ}C}$ is most uncertain; Siemonsen and Ulich[52] obtained a value of $-296{,}200 \pm 2000$ cal, but Bichowsky and Rossini recommend a value of $-330{,}000$ cal on the basis of all earlier work. Although Siemonsen and Ulich's results look somewhat more reliable, it is difficult to assess the absolute accuracy, which may be much less than they suggest. Their value of $\Delta H^{\circ}_{25^{\circ}C}$ has therefore been selected and the curve as a whole classed as *D*.

Thompson[54] gives an equation which exhibits a much smaller slope than that of the curve proposed here. It has been neglected as it is based on a fixed estimated value for the specific heat of V_2O_3 and has a slope which cuts right across the general pattern of the oxide lines.

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The Influence of Smoke and Atmospheric Absorption on Optical Pyrometry in Steelworks

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SYNOPSIS

Measurements have been made on the absorption of the atmosphere in a steel foundry and an open-hearth melting shop. The optical density of a 10-ft column of air has been found to vary between 0·004 and 0·03, corresponding to an error of from 1° to 8° C in an optical-pyrometer observation at 1450° C. Smoke arising from tapping or teeming operations may give rise to errors as high as 60° C. It is suggested that the correction for atmospheric absorption is likely to be between 2° and 6° C for each 10-ft distance between the pyrometer and a liquid-steel source, and the additional correction for local smoke will probably lie between 5° and 15° C, provided that the observer is experienced and takes care to sight in a direction which will make the effect of smoke as small as possible.

Introduction

In the course of some work now in progress on the emissivity of molten steel, measurements of brightness temperature made in the works have been compared with true temperatures determined by thermocouple. The brightness measurements were made by sighting on the steel from distances which varied from 10 to 40 ft (3 to 12 m), and comparison with laboratory determinations suggested that they might have been affected by atmospheric absorption. The present investigation has been carried out in order to estimate the magnitude of the effect.

The absorption may conveniently be studied in two parts: that of the column of air between the pyrometer and the steel stream, which will vary according to the distance from which the observation is made; and, independently, absorption by smoke surrounding the stream, which will not vary with the sighting distance.

METHOD OF MEASUREMENT

A tungsten-strip lamp at the principal focus of a lens was used as a source of radiation for the absorption measurements. The strip lamp was an experimental one, having a filament about 4 mm wide, and the lens was an achromat of about 10-in (25-cm) focus and 5-in aperture. It was, in fact, the front component of a 20-in $f/6{\cdot}3$ lens designed for aerial photography. This was protected from accidental splashing with steel by thin sheet-glass windows, which, while they impaired the definition considerably, did not measurably affect the uniformity of brightness of the image. The lamp and lens were mounted on a board supported by a substantial tripod, the lamp being connected by a heavy flexible lead to a portable control panel. Current was supplied from the A.C. mains at 230 V through two sliding resistances of 150 ohms and 1500 ohms in parallel (to give coarse and fine adjustments) to a step-down transformer feeding the lamp. A Weston 6-in sub-standard dynamometer ammeter was used in the secondary circuit, and the current was held constant by manipulation of the control resistances. The ammeter has a fine pointer and a mirror scale, and a lens mounted over the scale was used to enable the pointer to be held accurately on one of the scale divisions. With a normal A.C. supply there was no difficulty in doing this to an accuracy of better than one part in a thousand (equivalent to about 1° C at 1100° C), but on some supplies it was found to be impossible to use the fine-adjustment rheostat, and momentary fluctuations of considerably greater value were unavoidable. These fluctuations did not, in general, affect the accuracy as much as might have been expected, since the observer with the optical pyrometer could readily detect them and avoid taking a reading when the lamp had obviously gone momentarily out of control. Throughout the work, a current of 18·4 amp was used, and wherever the apparatus was set up, the brightness temperature was always within 2° of 1110° C. Normally, however, a 'close-up' reading was taken for each series of observations and this gave a datum accurate to about $\pm 0{\cdot}5°$ C.

The optical pyrometer used was a new instrument designed by Mr. C. R. Barber at the National Physical Laboratory,[1] and had sufficient magnification to make it possible to take readings on a 5-in dia source at distances up to about 100 ft. It was mounted on a tripod and carefully sighted so that the strip lamp was always observed at the level of the nick in the filament. This nick was visible at distances up to about 15 ft, and in order to secure accuracy of alignment at greater distances, the line of sight was determined by setting up a marker on another tripod in line with the nick at a distance of about 15 ft from the lens. This could be done to an accuracy of about $\frac{1}{2}$ in, whereas an error of about 2 in would have been necessary to cause a measurable difference in the brightness reading.

Atmospheric absorption was determined from the change in reading caused by removing the pyrometer from a position just in front of the lens to a more

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remote station, the ratio of the brightnesses R being given by the equation :

$$\log_{10}R = \frac{0{\cdot}6219}{\lambda}\left(\frac{10^4}{T_d} - \frac{10^4}{T}\right),$$

where λ is the effective wavelength employed ($0{\cdot}658\mu$), T the brightness temperature of the source in degrees K, and T_d the observed temperature at a distance of d ft. $\text{Log}_{10}R$, then, is the optical density of the column of d ft of the atmosphere. Observations were made at various distances, and the uniform criterion which has been chosen is :

$$D_{10} = \frac{10\log_{10}R}{d},$$

that is, the optical density of a column of 10 ft of atmosphere. In order that this may be converted into the effect on any desired temperature reading, the conversion from density to temperature correction has been given in Table I. For example, if a reading is taken at a distance of 25 ft, under conditions in which it is estimated that D_{10} is $0{\cdot}01$, the effective density will be $0{\cdot}025$, which will involve a correction to the reading of 4° if the observed temperature is 1000° C, or 7° if it is 1500° C.

In order to give some idea of the precision attained when conditions were moderately favourable as regards steadiness of the A.C. supply to the lamp, a set of observations by two observers on the absorption of 50 ft of air in the foundry at East Hecla Works is given in detail. Each optical-pyrometer value is taken as the mean of ten independent readings.

	Observer J.A.H.		Observer D.K.	
	Close-up, °C	50 ft, °C	Close-up, °C	50 ft, °C
	1107	1098	1109	1096
	1106	1095	1107	1096
	1107	1096	1108	1100
	1106	1097	1109	1094
	1107	1100	1108	1095
	1107	1100	1111	1101
	1108	1094	1110	1099
	1109	1097	1112	1100
	1110	1098	1108	1101
	1107	1093	1109	1102
Mean	1107·4	1096·8	1109·1	1098·2
$10^4/T$	7·244	7·300	7·235	7·292
$10^4/T_d - 10^4/T$	0·056		0·057	
D	0·053			
D_{10}	0·0106			

With the worst mains conditions encountered (Siemens melting shop, Vickers Works, where the cranes are operated from the A.C. supply), 3 successive sets of 10 readings by one observer gave means of 1109·8, 1107·1, and 1108·1° C, the extreme range of individual readings being from 1104 to 1117° C.

ATMOSPHERIC ABSORPTION

A series of isolated measurements of atmospheric absorption in different locations is set out in Fig. 1. The accuracy in D_{10} is estimated to be $\pm 0{\cdot}0005$ in the observations at the National Physical Laboratory and at East Hecla Works, and about $\pm 0{\cdot}001$ at Templeborough, where the A.C. voltage was less steady. In addition to D_{10}, the correction in degrees necessary for an observation on a source at 1450° C at a distance of 10 ft is shown on the graph. This value has been chosen as representing average conditions on a teeming stream.

Table I

CORRECTIONS TO OPTICAL PYROMETER READINGS ($\lambda = 0{\cdot}658\mu$) ON ACCOUNT OF DENSITY OF ATMOSPHERE AND SMOKE

Density of Smoke Plus Atmosphere	Correction to be Added to an Observed Temperature of :				
	1000° C	1200° C	1400° C	1600° C	1800° C
0·01	2	2	3	4	5
0·02	3	5	6	7	9
0·05	9	12	15	19	23
0·10	18	24	30	38	45
0·15	27	35	46	57	70
0·20	36	48	62	77	95
0·25	45	60	78	97	120
0·30	54	72	94	118	146
0·35	64	85	110	139	172
0·40	73	98	127	161	199

The observations at the National Physical Laboratory were taken on 8th March, 1948, the weather conditions being sunny with very faint haze. Out of doors, the absorption measured over a distance of 75 ft was almost inappreciable, $D_{10} = 0{\cdot}0006$. In a basement corridor, where the traffic is only three or four persons a day, D_{10} was measured as $0{\cdot}0015$, but in the ground-floor corridor of the same building, where someone passes every three or four minutes during the day, the value rose to $0{\cdot}0029$. On 25th February, when the weather conditions were overcast but clear, a measurement in a corridor, similar in dimensions and traffic, in the research laboratory at East Hecla Works, gave a value of $0{\cdot}0037$.

In the foundry at East Hecla, the atmosphere was appreciably denser, as the five individual observations show. The first three were taken within the space of a quarter of an hour on the afternoon of 23rd February. Critical observation of the appearance of the shop made it obvious that the atmosphere was clearing, but the change was not such as to force itself on the attention, and if an observer had been presented with the conditions represented by $D_{10} = 0{\cdot}0105$ and $D_{10} = 0{\cdot}0040$ on different occasions, it is very doubtful whether he would have been able to say that one condition was clearer than the other. A quarter of an hour later an even more rapid change in absorption was observed ; the 10 individual readings plotted in the first curve of Fig. 2 were taken in the space of 2 or 3 min. One observer took the readings while another recorded them and watched the shop conditions. The panel on which the lens acting as source was mounted was painted dull black, and it was noticed that when this was viewed from a distance of 50 ft its appearance changed from greyish to something more nearly black during the observations.

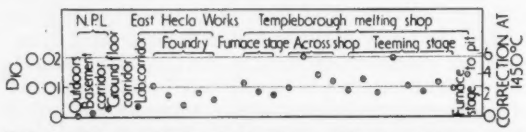

Fig. 1—Atmospheric absorption : Single observations

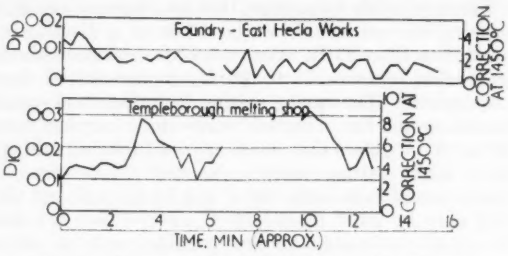

Fig. 2—Atmospheric absorption : Continuous observation

This change is shown in the curve as a reduction in atmospheric density to about two-thirds of its original value.

The second curve of Fig. 2 shows a somewhat similar effect observed on 24th February. This set of observations was taken during the last few minutes before noon, and a good deal of the work in the foundry was being shut down for lunch ; the effect is obvious in the graph. During the lunch interval however, a heat from a high-frequency furnace near the line of sight was tapped, and during the long series of observations plotted in the third graph of Fig. 2, casting operations from shanks were being carried out quite close to the line of sight. Local production of smoke has caused the observed values of the absorption to be noticeably more erratic. The last two foundry observations recorded in Fig. 1 were taken at 11.30 a.m. on 24th February.

The weather conditions on these two days, as recorded at the meteorological station in Weston Park (some 4 miles (6 km) distant and 250 ft (75 m) higher than the works) were overcast with a wind speed of about 7 m.p.h. on the 23rd, and cloudy with a wind speed of about 2 m.p.h. on the 24th. Visual observation in the foundry suggested that conditions on both days were distinctly clearer than average.

The remainder of the observations in Fig. 1 were taken on 1st, 2nd, 3rd, and 4th March in the Templeborough melting shop of The United Steel Companies, Ltd. Weather conditions on all these days were foggy with an easterly wind of about 2 m.p.h., except on the 1st, when there was no wind. The effect of fog outside on the clearness of the atmosphere in the shop appeared to be negligible ; presumably the temperature was sufficiently high to disperse it completely.

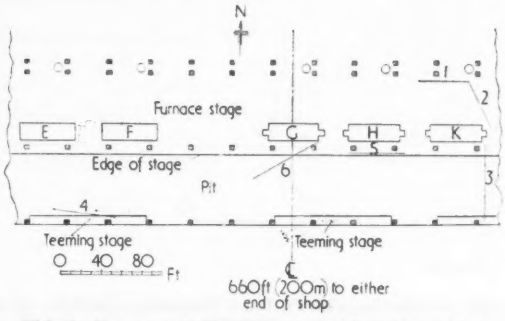

Fig. 3—Lay-out of Templeborough melting shop

The layout of the shop and the positions in which atmospheric-absorption measurements were made are shown in Fig. 3. Nine of the 14 furnaces in the shop were in operation at the time, 3 (*B*, *G*, and *H*) being gas-fired and the remainder oil-fired. *K* furnace was among those which were shut down. The first of the 3 observations made on the furnace stage and recorded in Fig. 1, was made over the 50-ft length marked 1 on the plan. The wall of the shop is open to the covered scrap-yard between the stacks of *H* and *K* furnaces, and, though no wind was recorded in the open at Weston Park, there was an appreciable breeze blowing in between the stacks. In consequence, the air was clearer here than anywhere else in the shop Nevertheless, D_{10} was found to be 0·0116—a value higher than any obtained in the East Hecla foundry. The second observation was a repeat on the next day. while the third was taken over the length marked 2 on the plan.

The group of 4 observations in Fig. 1 marked " across shop " was taken over the 77½-ft length marked 3. Between the furnace and the teeming stages are lines of railway, and the state of the atmosphere above the casting pit depends very much on the traffic on these lines through it. In describing the appearance of the atmosphere, the terms " clear," " normal," and " smoky " are used. Under clear conditions, in the absence of sunlight or other strong light, the shadow under the furnace stage appeared black when viewed from the teeming stage ; under normal conditions it appeared slightly grey, and contrast was appreciably less than in objects close at hand ; under conditions described as smoky there was visible smoke intervening between the two stages. The first observation plotted was made under clear conditions, and the second under smoky conditions, immediately after the passage of a locomotive which left visible smoke behind it. For the third and fourth observations .conditions were normal. The fourth point represents the mean of 4 sets of 10 readings taken in rapid succession and giving values of 0·0132, 0·0112, 0·0129, and 0·0108. During the fourth of these sets *L* furnace was tapped, and though the tap-hole was only some 40 ft away from the line of sight, no increase in absorption was observed, the smoke rising rapidly to the roof above the hot metal.

The effect of smoke from locomotives is obviously much more serious, and further evidence of this is provided by the last two curves of Fig. 2, which cover periods of about 6 and 3 min. In the first of these, a locomotive passed during the observations ; and the second series was started immediately after a locomotive had passed. The slow dispersal of the smoke over a period of about 2 min. can be seen clearly. The value of D_{10} in these circumstances has not, of course, any precise significance, since there would be marked variations in the density of the atmosphere along the path over which the observations were made.

The seven observations in the next group were taken along the teeming stage in the position marked 4 in Fig. 3. They were made over a length of 61 ft in connection with observations on the smoke arising from teeming operations. In spite of the fact that there is now no periodic emission of smoke in the direct line of sight, the variations in density are of the

same order as those observed across the pit, and it is certain that an optical-pyrometer observer taking readings on casting operations would not be conscious of the changes in atmospheric transmission.

The last observation in Fig. 1 was made over the 53-ft length marked 6, when a sight was taken from the pit, looking upwards to the furnace stage. This observation was made in connection with a measurement of the smoke arising from the tapping of *G* furnace.

ABSORPTION BY LOCALIZED SMOKE

Measurements of the effect of absorption by the smoke arising from tapping and teeming operations were made by setting up the lamp and the pyrometer on opposite sides of the job and as near to one another as was conveniently practicable. Readings over this distance were taken in the absence of local smoke, normally both before and after the operation to be

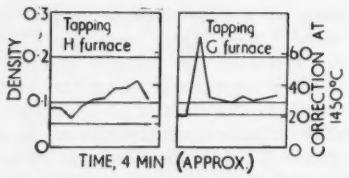

Fig. 4—Smoke absorption : Basic open-hearth tapping streams

studied, and a close-up reading was also taken. In this way the density of the atmosphere of the shop could be assessed separately from that of the smoke arising from the job. If the smoke were uniformly distributed around the steel, the absorption effective when the steel was being observed would be half the value found in this way, but a skilled observer will normally be able to select a sighting point which will give a lower value than this by taking advantage of the wind.

Figure 4 shows the results obtained during the tapping of *H* and *G* furnaces at Templeborough. The observations on *H* furnace were made on 3rd March over the length marked 5 on the plan. The line of sight was 6 ft 6 in above the launder and 11 ft from the back wall of the furnace. The steel being made was of 0·08% C, and no coal was added in the ladle. The sight for the *G* furnace heat on the next day was made over the distance marked 6. The line of sight passed about 2 ft 6 in above and 1 ft 6 in beyond the end of the launder, so that smoke arising from the ladle, rather than from the launder, would be effective. The steel was of 0·54% C and the observations were made during the first 3½ min of tapping before the coal in the ladle ignited. When the flame had subsided no further observations were possible because of obstruction by the crane. Each point on the curves of Fig. 4 represents a single reading of the pyrometer, and the densities and temperature corrections, calculated for an observed temperature of 1450° C, are relative to a close-up reading of the source. The horizontal line represents the effect of the shop atmosphere at the time. The column of air involved was 50 ft long for the *H* furnace observations and 53 ft for those on *G* furnace.

Since it is fair to assume that an observation on a tapping stream would not be made at a distance of much less than 25 ft, there would be an unavoidable correction of from 7° to 10° C on account of shop atmosphere. The smoke arising from the steel would then account for a further correction, varying from 5° to 15° C, unless the observer could take advantage of a fairly strong wind. Normally, therefore, a correction of just under 20° C will be needed, but this will vary by more than ± 5° C, even if care is taken to avoid noticeably smoky periods, such as those represented by the third reading on the *G* furnace heat.

An observation made in the foundry at East Hecla across the stream during the lip-pouring of a large manganese-steel casting gave densities ranging from 0·027 to 0·113 above that of the shop atmosphere ; the line of sight relative to the stream was similar to that used during the tapping of *G* furnace. The comment of the observer D.K. on the latter observation was, " not maximum smoke, but pretty bad." The density of 0·113 is equivalent to a correction of about 30° at 1450° C.

The results of two experiments on uphill casts from stopper ladles at Templeborough are shown in Fig. 5, the situation in the shop being indicated as position 4 in Fig. 3. In each experiment the cast consisted of

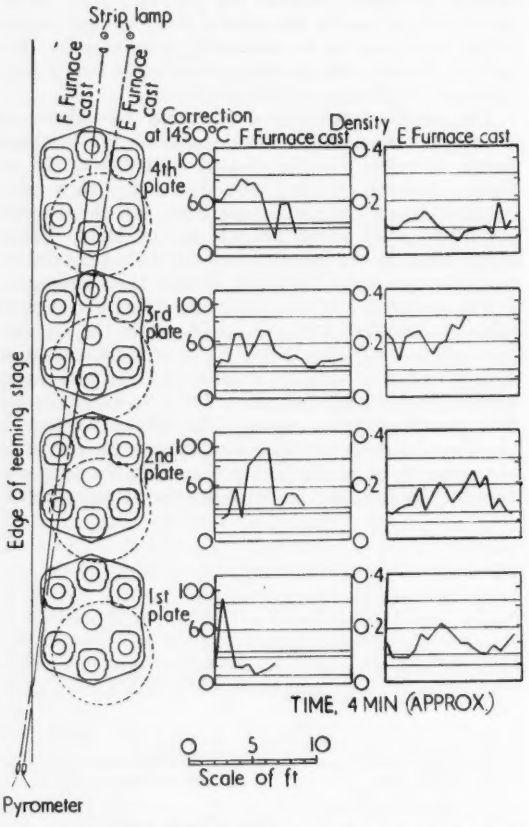

Fig. 5—Smoke absorption : Teeming clusters of six ingots

four plates, each of six ingots, which are drawn to scale in Fig. 5. The position of the ladle while teeming each plate is shown by a broken line, and the two lines of sight are also indicated. Both heats were of rimming-steel quality, but the effervescence was suppressed in the *F*-furnace cast by means of aluminium, and in the *E*-furnace cast by means of cooler plates. The moulds were of the semi-closed top type and had been tarred for the *E*-furnace cast, but not for the *F*-furnace cast.

The curves in Fig. 5 are plotted on the same basis as those of Fig. 4. Considering first the curves for the *F*-furnace cast, it will be seen that there are two lines representing the effect of the shop atmosphere. The lower of these, corresponding to a correction of 8° C over the 61-ft path, represents the conditions at the start of teeming, while the other line, showing a correction of 35° C, gives the value found after teeming was completed and all local smoke had died down. There was thus a change in atmospheric conditions which would have corresponded to an apparent temperature change of nearly 5° C during the operation, had the observations been made at a normal distance of 10 ft. For the observations on the first plate, the line of sight passes well to the left of the ladle, and, as might be expected, there is not much interference by smoke, except for one or two abnormal readings. For the second plate, the line of sight passed over two of the moulds, one of which was under the ladle, and the effect is considerably greater, at times producing an error of about 60° C, even if the higher value for the shop atmosphere correction is taken. For the third plate, there is only one smoking mould in the line of sight and the effect is less ; the same remark applies to the last plate, as the centre mould on the side of the plate towards the pyrometer was stopped off.

When the observations on the *E*-furnace cast were made, the atmospheric conditions were stable, so that there is greater certainty of the effect of the local production of smoke. The line of sight was not exactly horizontal, for the strip lamp was somewhat higher than the pyrometer, and it was found that by the time the third plate was reached, the line of sight was only just clear of the bottom of the ladle. This fact accounts for the very high absorption shown by the observations on the third plate, since there was a considerable amount of smoke trapped under the ladle. This effect had been noticed previously and recorded photographically.[2] Before the fourth plate was teemed, the ladle was raised by about a foot, and the marked reduction in the absorption is obvious. There was, however, another reason which contributed to this improvement. Once again, the nearest ingot on the last plate was stopped off, and in consequence the line of sight did not pass directly over any mould which would be emitting smoke. Even so, on the average, there is an error of some 10 or 15° to be attributed to the local production of smoke.

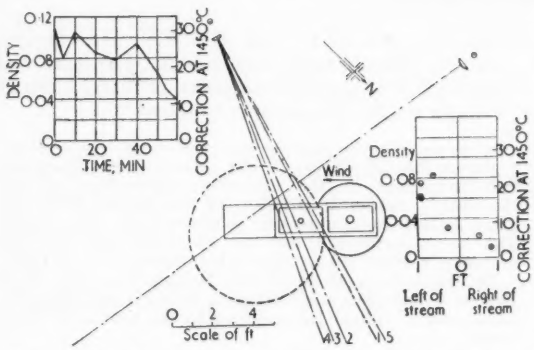

Fig. 6—Smoke absorption : Teeming single ingot through trough

These experiments suggest that when clusters of ingots are being teemed, a skilled observer, by careful choice of his line of sight, should be able to avoid errors exceeding 10° C on account of local smoke, though there might be an additional error of at least 5° C because of the effect of the shop atmosphere. On the other hand, unless great care is taken, errors of 30 or 40° could easily occur without arousing the suspicions of the observer.

Two other experiments were made on stopper-ladle casts into large ingots on the acid Siemens plant of the Vickers Works of the English Steel Corporation, Ltd. In both the heats concerned, teeming was by way of a trough. The arrangement is drawn to scale in Fig. 6, the ladle again being indicated by a broken line. Since ample time for observation was available, and single readings in this shop were unreliable on account of the unsteadiness of the A.C. supply, each point on the curves of Fig. 6 represents the mean of a set of 10 readings.

In the first experiment a carbon steel (0·39% C) was being cast. A single line of sight, roughly east–west, was used, and observations were taken at intervals during the 57 min occupied by the teeming. Though the meteorological observations indicated a wind of 9 m.p.h. from the east, there was quite a strong breeze blowing in from the open end of the shop in the direction marked in Fig. 6. The line of sight therefore, should record more than double the amount of smoke which would have been effective in sighting on the stream from the windward. The steel entered the head of the mould after 40 min, and a marked drop in the amount of smoke is apparent at this stage.

For the second experiment the steel was of 0·22% C. Five different lines of sight, roughly north–south, were used, and the numbers on the plan indicate the order in which the observations were made, three observations having been made in position 4. The observation in position 5 was taken right at the end of teeming when smoke would be at a minimum. The absorption recorded on sights 1 and 5 is probably not very different from that which would have been experienced had the stream itself been under observation from the windward—that is, a correction of about 5° C would probably be necessary under the best conditions of observation. This is in addition to any effect of absorption by the atmosphere of the shop, since the values plotted in Fig. 6 are shown relative to readings taken at the same distance as those used for the smoke-absorption observations. Atmospheric-absorption measurements were not made in this shop on account of the unsteadiness of the

A.C. supply, but the smoke-absorption figures shown in Fig. 6 are probably good to about $\pm 3°$ C.

CONCLUSIONS

Atmospheric absorption and the effect of smoke arising from the operation under observation can both cause appreciable errors in optical pyrometry under works' conditions. Expressed in terms of the error introduced into an observation on a brightness temperature of 1450° C, the lowering of the readings may be summarized as follows :

Atmospheric Absorption—2° C for each 10 ft between the pyrometer and the source of radiation under very good conditions, rising to 6° C for fairly smoky conditions.

Smoke from the Operation Observed—This will depend very much on the skill of the observer in selecting his line of sight. The following values are minima based on the assumption of considerable experience : (i) Tapping streams and lip-poured casting streams, 5° to 15° C. (ii) Stopper-ladle casting streams, single ingot, 5° C. (iii) Stopper-ladle casting streams, clusters of ingots bottom-fed, 10° C.

In order that full advantage may be taken of the skill of the observer in avoiding smoke, it is important that it should be easy for him to be able to detect its presence while he is sighting through the optical pyrometer. To that end, it is very desirable that the optical system of the pyrometer should be designed so as to give a bright, clear image as free from any trace of 'milkiness' as possible. Under these conditions, in the absence of smoke, the parts of the field around the bright source will appear very dark, but will immediately appear luminous when light is scattered by smoke. Precautions in design that suggest themselves are the blooming of glass-air surfaces and the reduction, as far as possible, of spherical aberration in the optical system. In this connection also, the use of a pyrometer lamp in which an opaque pointer is used to mark the sighting point on the filament offers a distinct advantage, since, in the absence of smoke the pointer is invisible against the dark ground, whereas it shows up more and more clearly as scatter by smoke increases.

Acknowledgments

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The Atmospheric Corrosion of Iron and Steel Wires

By J. C. Hudson, D.Sc.

SYNOPSIS

The results of tests on the corrosion of ferrous wires when exposed in an industrial atmosphere for periods of up to 10 years are reported. The rate of corrosion did not vary appreciably with duration of exposure, but was affected by the diameter of the wire, being greater for thin than for thick wires. Certain wrought irons and low-alloy steels proved much more resistant than mild steel.

The practical consequences of these observations are discussed, and it is suggested that considerable economies would accrue from the substitution of low-alloy steel wire for mild-steel wire, where resistance to atmospheric corrosion is required and other circumstances permit.

Introduction

THE main method of determining corrosion adopted by the Corrosion Committee for their investigations of the atmospheric corrosion of ferrous metals in the field has been the measurement of the losses in weight of massive specimens of plate or flat. In certain cases, these observations have been supplemented by parallel exposure tests on specimens of the same materials, prepared either in the form of wire or of mechanical test-pieces, the corrosion of which is deduced from the decrease in breaking load that results from rusting. Two series of tests of this type, using wire specimens, were commenced between 1931 and 1935, namely :

(1) Tests on seven different materials exposed in the form of both 10- and 3½-S.W.G. wires at two stations, Farnborough and Calshot. Exposure was begun in 1931 and was completed in 1936. A report on the results has already appeared.*

Paper MG/BB/12/48 of the Atmospheric Corrosion Sub-Committee of the Corrosion Committee of the Metallurgy (General) Division of the British Iron and Steel Research Association, received 25th May, 1948. The views expressed are the author's, and are not necessarily endorsed by the Sub-Committee as a body.

Dr. Hudson is Head of the British Iron and Steel Research Association's Corrosion Laboratory, Birmingham, and is Official Investigator to the Corrosion Committee.

* Fifth Report of the Corrosion Committee : *The Iron and Steel Institute*, 1938, *Special Report No.* 21, p. 249.

(2) In 1935 wires of 15 materials were exposed on a roof at Sheffield University, where facilities were kindly afforded through the courtesy of Professor J. H. Andrew. All were tested as 10 S.W.G., most of them as 3½ S.W.G., and a few as 16 S.W.G. Wires of four other materials were added to the test racks in 1937, when it proved necessary to replace a number of original specimens that had been lost from the site. This series of tests was continued until 1947, sets of specimens being removed at intervals up to a maximum exposure period of 10 years. The results are given in this report.

EXPERIMENTAL

MATERIALS TESTED

The materials included in the second series of wire tests and details of their analysis are given in Table I. The materials may be classified broadly into four groups as follows :

(1) Unalloyed carbon steels, including three samples of ordinary mild steel, rail steel, ingot iron, and Aston-Byers iron. These last two materials are virtually mild steels with a very low carbon content
(2) Unalloyed wrought irons of two types, namely, Staffordshire and Swedish
(3) Various low-alloy steels containing small percentages of copper and/or chromium
(4) Copper-bearing Staffordshire wrought irons.

The microstructure of the wires presented no unusual feature and may be described broadly as a ferritic-pearlitic structure distorted by cold work.

METHODS OF PREPARING THE SPECIMENS

Wire rods of 2 S.W.G. in each of the various materials were prepared from the original heats or casts used for the main loss-in-weight investigations by appropriate methods.* These rods were drawn to 3½ S.W.G., and the necessary lengths of wire for the specimens of this gauge were cut off ; the remainder was then drawn to 10 S.W.G., passing through 5½-, 7-, and 8½-S.W.G. holes. Where materials were also tested at 16 S.W.G., sufficient 10-S.W.G. wire was close-annealed at about 750° C and then drawn down to 16 S.W.G., passing through 11½-, 13-, and 14½-S.W.G. holes.

METHODS OF TESTING

The method of testing consisted of cutting the wire into 9-in lengths, each of which constituted a specimen. In order to obtain sufficiently accurate results, it was necessary to expose six similar specimens of each material per determination. At the conclusion of the period of exposure the breaking loads of each of a set of six specimens were determined and

* Third Report of the Corrosion Committee : *The Iron and Steel Institute*, 1935, *Special Report No.* 8, p. 187.

Table I

ANALYSES OF THE MATERIALS TESTED AND BREAKING LOADS OF THE WIRES

Material		Analysis, %*								Breaking Load, lb		
Description	Code Letter	C	Mn	Si	P	S	Cr	Cu	Ni	½ S.W.G. (0·242 in)	10 S.W.G. (0·128 in)	16 S.W.G. (0·063 in)
Ordinary mild steel	X	0·22	0·58	0·02	0·039	0·039	Trace	0·03	0·09	4632	1766	401
	X2	0·23	0·59	0·01	0·031	0·026	0·06	0·025	0·03	4292	1724	...
	XK	0·21	0·58	0·10	0·42	0·032	0·09	0·02	0·03	4563	1676	...
Ingot iron	E	0·03	0·02	0·002	0·013	0·043	Nil	0·03	0·03	...	1115	...
Rail steel	F	0·55	0·61	0·16	0·019	0·037	Trace	0·03	0·07	6583	2480	...
Aston-Byers iron	H	0·02	0·02	0·13	0·144	0·008	0·003	<0·01	<0·01	3470	1247	...
Staffordshire wrought iron	D	0·03	0·02	0·10	0·138	0·016	Nil	0·04	0·07	...	1242	...
	DA	0·04	0·05	0·16	0·35	0·016	...	0·05	0·07†	3728	1428	349
	DC	0·04	0·04	0·14	0·34	0·018	...	0·06	0·07†	3986	1474	360
Swedish wrought iron	J	0·04	Nil	0·02	0·054	0·008	Nil	Trace	Nil	2925	984	...
Copper-bearing mild steel	O	0·24	1·53	0·34	0·036	0·035	0·035	0·52	0·02	5747	2173	...
	Y	0·22	0·57	0·02	0·037	0·039	Trace	0·23	0·08	4790	1810	...
	ZK	0·23	0·60	0·115	0·035	0·026	0·06	0·50	0·03	4732	1811	...
Copper-bearing Staffordshire wrought iron	DB	0·04	0·04	0·14	0·27	0·011	...	0·30	0·07†	3665	1393	330
	DD	0·03	0·05	0·11	0·23	0·014	...	0·28	0·07†	3654	1386	319
Chromium steel (Cr 1%)	K	0·27	0·59	0·125	0·042	0·031	0·98	0·02	0·04	5297	2108	...
Chromium–copper steels	L	0·26	0·60	0·13	0·038	0·026	0·59	0·47	0·04	5127	1980	...
	M	0·28	0·89	0·15	0·038	0·027	0·59	0·47	0·03	5753	2200	...
	N	0·28	0·83	0·135	0·043	0·038	0·92	0·47	0·04	5580	2134	...

* In most cases the analyses are not of the actual wires, but of the same materials as supplied for test in other forms
† Assumed the same as for the similar material D

the average value was compared with that for six similar specimens which had been stored in the laboratory and had suffered no corrosion. As a rule provision was made for tests over consecutive periods of exposure by exposing two or more similar sets of specimens which were removed at different times.

In the most recent work, the specimens have been weighed before exposure and reweighed at the end of the test after all loose rust has been removed, so as to obtain an approximate figure for the loss in weight. The final average diameters of the corroded wires have also been measured. Detailed figures will not be given here for these loss-in-weight and loss-in-diameter determinations, as the main method of investigation is the measurement of the decrease in breaking load. In general, the correlation between the three series of observations was good.*

METHOD OF EXPOSURE

The method of exposure simply consisted of mounting the specimens horizontally in wooden frames, which were supported at a height of about 2 ft 6 in above the roof level of the testing station. The specimens were spaced at a suitable distance apart by means of distance pieces inserted between their ends.†

Exposure on the roof of the Metallurgy Department of Sheffield University was begun on 10th January, 1935, and the first set of specimens was removed two years later in January 1937. Provision had been made for tests on other sets of specimens to be exposed for periods of five and ten years, respectively. Unfortunately, these were lost from the exposure station shortly after the end of the two-years' period. The lost specimens were replaced as far as possible by similar sets exposed in April 1937, when specimens of 10-S.W.G. and 3½-S.W.G. wires of four other materials were added. Some of the latter remained exposed until April 1947, when the tests were concluded after 10 years' exposure.

It should be noted that in April 1937, the frames were moved to another roof at Sheffield University where the conditions may have differed in corrosiveness. Some indication of the atmospheric pollution at both exposure sites during the test periods concerned is given by the results for the corrosion of small control pollution specimens of ingot iron and zinc, which were exposed there (*see* p. 279). It is improbable that the difference between the corrosiveness of the atmosphere at the two stations exceeded 20%.

OBSERVATIONS DURING EXPOSURE

Reference was made in an earlier report‡ to differences in the colour of the rust developing on the different materials, the general tendency being for this to be darker on the copper-bearing materials. This observation has been confirmed with a few exceptions throughout the whole test period, and at the last inspection made in the laboratory on the return of the specimens after 10 years' exposure, the rust colour, assessed in terms of a standard scale, was, on the average, significantly darker on the copper-bearing materials than on those free from copper. As will be shown later (*see* p. 282), the former materials were also the more corrosion-resistant.

Table II

TYPICAL SET OF RESULTS FOR 3½-S.W.G. MILD-STEEL WIRE X EXPOSED FOR 10 YEARS

Specimen No.	Breaking Load, lb	
	Unexposed Wire	Exposed Wire
1	4620	1610
2	4630	1640
3	4610	1620
4	4520	1630
5	4640	1580
6	4580	1630
Average	4600	1618
Standard deviation	40·4	19·5

RESULTS

METHOD OF EVALUATION

A typical set of results is set out in Table II. This refers to the 3½-S.W.G. specimens of ordinary mild steel X exposed for 10 years, from 1937 to 1947. It will be seen that the average breaking load of the unexposed wire was 4600 lb, with a standard deviation of 40·4 lb ; that of the exposed wire was 1618 lb, with a standard deviation of 19·5 lb. The loss in breaking load due to corrosion was, thus, 2982 lb and the standard deviation of this difference, 44·9 lb.

The question of the reproducibility of the results will be discussed later (*see* p. 283). Meanwhile, it may be noted that, according to the theory of statistics, there is a 400 to 1 chance that the true loss in breaking load on exposure does not differ by three times the standard deviation, *i.e.*, by 134 lb from the observed value. This figure of 134 lb represents 3% of the original breaking load. As the degree of corrosion is deduced from the loss in diameter, it follows that there is a 400 to 1 chance that the experimental error does not exceed 1·5%.

In presenting the detailed results for the individual materials, the corrosion will be expressed in terms of the equivalent reduction in radius over the whole period of exposure. This reduction has been calculated as follows :

$$t = r(1 - \sqrt{B_E/B_B})$$

where r is the original radius of the wire in mils, B_B is the breaking load of the unexposed wire in pounds, and B_E is the breaking load of the exposed wire in pounds. In the example given, $r = 242/2 = 121$, $B_B = 4600$ and $B_E = 1618$. Consequently :

$$t = 121(1 - \sqrt{1618/4600}) = 121(1 - 0{\cdot}5932) = 49{\cdot}2$$

RESULTS OF THE TESTS ON WIRES

A complete statement of the results of the tests, calculated in the manner described, will be found in

* A typical example of this will be found in the Fifth Report of the Corrosion Committee, *loc. cit.*, p. 261.

† The distance between adjacent wires of a set was approximately ¼in. for 3½-S.W.G. wires and ⅛in. for wires of smaller diameter. The distance between sets was approximately ½in. The ends of the wires grasped in the frame were painted for a length of about 1½in. to protect them from rusting, different combinations of colours being used for identification purposes.

‡ Fifth Report of the Corrosion Committee, *loc. cit.*, p. 257.

Table III

RESULTS OF THE ATMOSPHERIC-CORROSION TESTS ON WIRES AT SHEFFIELD UNIVERSITY

Material		Equivalent Reduction in Radius due to Corrosion, mils								
		3½-S.W.G. Wires		10-S.W.G. Wires						16-S.W.G. Wires
Designation	Code Letter	1935–40	1937–47	1935–37	1937–39	1935–40	1937–42	1937–44	1937–47	1935–37
Ordinary mild steel	X	23·5	49·3	13·6	...	31·0	...	38·3	...	16·7
	X2	23·3	...	14·2	10·6	...	...	...	...	...
	XK	...	44·5	13·4	...	28·9	...	36·1	...	...
Ingot iron	E	...	...	...	12·1	...	...	...	...	...
Rail steel	F	...	37·8	...	9·7	...	...	...	...	...
Aston-Byers iron	H	...	47·3	...	10·9	...	27·6	40·3	...	...
Staffordshire wrought iron	D	...	...	...	8·0	...	...	...	...	...
	DA	14·8	29·8	9·1	...	19·8	...	...	35·0	12·4
	DC	14·1	26·9	8·8	...	19·0	...	...	...	9·8
Swedish wrought iron	J	...	65·9	15·1	...	37·2	37·3*	...	...	...
Copper-bearing mild steel	O	...	27·4	8·7	...	20·1	...	...	33·5	...
	Y	14·0	...	9·0	...	...	...	...	...	...
	ZK	...	23·9	8·5	...	18·1	...	...	33·7	...
Copper-bearing Staffordshire wrought iron	DB	11·8	24·0	6·6	...	17·9	...	...	31·9	10·3
	DD	12·1	23·9	6·5	...	15·6	...	...	31·3	9·1
Chromium steel (Cr 1%)	K	...	36·0	10·6	...	24·1	...	...	38·3	...
Chromium–copper steels	L	...	25·3	7·2	...	15·3	...	...	27·8	...
	M	12·4	...	7·8	...	...	...	...	...	...
	N	...	23·8	6·8	...	14·3	...	...	21·9	...
Relative corrosion of ingot iron pollution specimens over the exposure period	...	103	97	114	96	103	91	89	97	114

* 5·5 years' exposure

Table III.* Although the original programme did not provide for all possible combinations of material, gauge, and duration of exposure, some of the gaps in Table III are due to the loss of specimens and others to the fact that certain materials had to be removed prematurely as they would not have withstood corrosion over the contemplated period.†

ATMOSPHERIC POLLUTION MEASUREMENTS

In order to illustrate the fluctuations in the severity of the conditions of exposure throughout the test, the results of observations made on "pollution" specimens exposed at the same site are shown in Table IV. These are small specimens of ingot iron and of zinc, which are used to determine the relative intensity of the corrosive conditions at the Corrosion Committee's atmospheric-exposure stations. Duplicate specimens of both materials are exposed for consecutive periods of one year. The size of specimen is 4 in × 2 in × approximately $\frac{1}{8}$in. thick in the case

* Small corrections have been applied, where appropriate, for deviations of the diameter of the wire from the average value for all the materials. It is for this reason that the figure for material X given on p. 278 as 49·2 mils becomes 49·3 mils in Table III.

† This applies to the specimens of Swedish wrought iron removed after 5·5 years' exposure, and those of Aston-Byers iron, and mild steels X and XK, removed after 7 years.

Table IV

LOSSES IN WEIGHT OF CONTROL POLLUTION SPECIMENS EXPOSED AT SHEFFIELD UNIVERSITY

Period of Exposure	Loss in Weight, mg/specimen/year*	
	Ingot Iron	Zinc
Jan. 1935–Jan. 1936	11324	562
,, 1936– ,, 1937	11861	674
,, 1937– ,, 1938	10122	570
,, 1938– ,, 1939	9657	235
,, 1939– ,, 1940	9658	269
,, 1940– ,, 1941	8432	343
,, 1941–Feb. 1942	9226	366
Feb. 1942–Jan. 1943	9638	283
Jan. 1943– ,, 1944	6514	233
,, 1944– ,, 1945	10375	246
,, 1945– ,, 1946	11325	207
,, 1946– ,, 1947	12940	317
,, 1947–end Apr. 1947	12940†	317†
Average for the whole period	10166	358

* The total area of specimen is 112·8 sq.cm. for ingot iron and 107·1 sq.cm. for zinc. The equivalent corrosion rates in mils per 1000 mg loss are 0·4449 for ingot iron and 0·5135 for zinc

† Assumed equal to the previous year, and weighted by ½ when computing the average

of ingot iron, and 0·05in. thick in that of zinc. The losses in weight of the specimens are determined at the end of each year's exposure after removing the corrosion products by suitable methods.*

The results given in Table IV show that appreciable changes occurred in the rate of corrosion of these pollution specimens from one year to another. The marked decrease observed after the first 2 years' exposure can no doubt be attributed, in part, to the removal of the specimens to a new site in April 1937, but similar fluctuations have been observed at other stations, where no change of site has occurred and are an inevitable result of variations in the local conditions over a period of years.

There would be little point in considering in detail the fluctuations shown in Table IV, as the correlation between the losses in weight of the ingot iron and of the zinc specimens, respectively, is poor. It is clear that over the middle period from 1938 to 1944, conditions were less severe than at the beginning or at the end of the tests. As an indication of the variation in corrosive conditions throughout the test, figures for the relative corrosion rate of the ingot-iron pollution specimens over the period to which each column of test results relates are given in the last line of Table III. These figures have been calculated by expressing the average rate of loss in weight over the period concerned as a percentage of the average rate of loss over the whole duration of the tests from 1935 to 1947.†

It will be seen that the fluctuations from the average value range from + 14% to − 11%. It is probable that the effects of the corrosion rate over individual periods would be less marked than these figures indicate, because variations in the corrosive conditions have a greater influence on the rate of rusting of freshly exposed specimens than on that of old ones ; in the latter case, the presence of rust on the corroded surfaces tends to reduce the effect of changes in the ambient conditions.

DISCUSSION OF RESULTS

VARIATION OF THE RATE OF CORROSION WITH TIME

In Fig. 1‡ the observed figures for the corrosion of 10-S.W.G. wires of six types of material are plotted as a function of the duration of exposure. In this diagram no distinction has been made between different periods of exposure, *i.e.*, the fact that some of the exposures were begun in 1935 and others in 1937 has been disregarded. Moreover, for the purpose of clarity, average figures for the ordinary Staffordshire wrought irons and the copper-bearing steels have been plotted. These materials did not differ markedly in corrosion resistance ; the results for the copper-bearing steels would be slightly above, and those for the wrought iron slightly below, the average curve.

It is clear from Fig. 1 that, taking into consideration the fluctuations in the corrosiveness of the atmosphere discussed in the previous section, no serious error would be made by concluding that over periods of up to 10 years the corrosion of ferrous wires exposed horizontally is, for all practical purposes, directly proportional to the duration of exposure.§ On this assumption the rate of corrosion of 10-S.W.G. wires of ordinary mild steel in the atmosphere at Sheffield University may be assessed in round figures at 6 mils/year on the radius, *i.e.*, 12 mils/year reduction in diameter.

EFFECT OF THE GAUGE OF THE WIRE

The results confirm earlier observations that the rate of corrosion of a given material is affected by the gauge of the wire, and increases as the diameter decreases. For example, referring to Table III, the corrosion of ordinary mild steel X after two years was 16·7 mils when tested as 16-S.W.G. wire, but 13·6 mils when tested as 10-S.W.G. wire, and after five years' exposure, the corrosion was 31·0 mils for 10-S.W.G. wire as compared with 23·5 mils for 3½-S.W.G. wire. This effect of the diameter of the material may also be illustrated by the corrosion–time curves for the copper-bearing Staffordshire wrought irons DB and DD (mean value for both materials) shown in Fig. 2 ; the curve for the 16-S.W.G. wires lies above that for the 10-S.W.G. wires, and the latter above the curve for the 3½-S.W.G. wires.

In all probability, the cause of this variation in the rate of corrosion with diameter is the accumulation of drops of rain water and dew at the lowest points of the specimens.‖ It would seem that the effect of these drops is more marked in the case of thin wires than of thick ones. Evidence of local attack

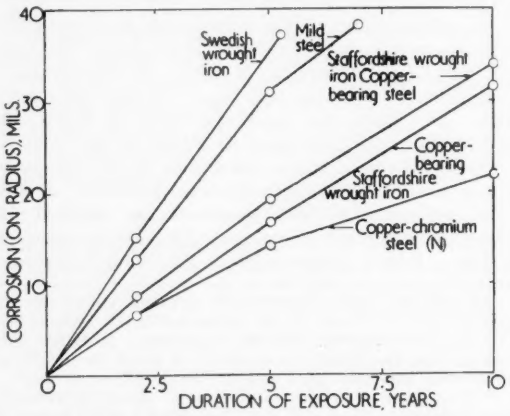


Fig. 1—Corrosion of 10-S.W.G. (0·128-in. dia) wires exposed to the atmosphere at Sheffield University

* A fresh set of specimens is exposed every year.

† The calculations have been based on the results for ingot iron rather than on those for zinc, as the former are more appropriate to ferrous materials.

‡ In preparing Fig. 1, the results for two or three similar materials of the same type have been averaged, *e.g.* the results shown for the Staffordshire wrought iron are average figures for materials D, DA, and DC.

§ The linear relation holds good more exactly for the period from 2·5 to 10 years, *i.e.*, there is some evidence that the rate of rusting is above the average in the early stages of exposure.

‖ It is possible that the differences in the degree of cold working of the wires may have some effect, as has been suggested to the author by Mr. A. T. Adam. A few tests made by the author on non-ferrous wires of the same diameter, but in differing degrees of hardness, seem to indicate that this is, at most, a secondary factor.

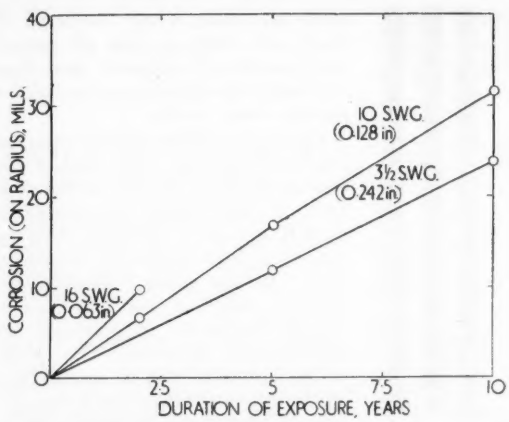


Fig. 2—Effect of gauge of wire on atmospheric corrosion

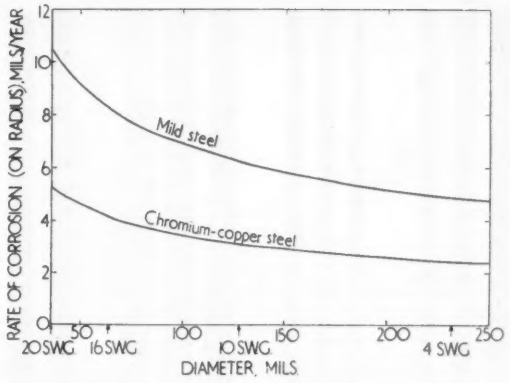


Fig. 3—Effect of the gauge on the rate of corrosion of steel wires in the atmosphere

at the lowest points on coils of copper wire exposed horizontally was obtained in the course of some tests in which the progress of corrosion was followed by measuring the electrical resistance of the specimens.* In this case, the total reduction in radius after about $2\frac{1}{2}$ years' exposure at South Kensington was 0·88, 0·84, 0·81, and 0·79 mils for copper wires of 28, 32, 36, and 40 mils dia (22, 21, 20, and 19 S.W.G.), respectively. Indications of a similar tendency for corrosion to increase with decreasing diameter of the wire were also observed in the case of copper wires tested by the decrease-in-breaking-load method ; the rates of corrosion over a period of 5 years of copper wires 97, 80, and 66 mils in dia† were found to be 0·121, 0·144, and 0·156 mils/year, respectively.

The results of the present tests on ferrous wires varying from 63 to 242 mils dia, can be expressed approximately by an equation of the type $t = Ad^k$, where t is the rate of corrosion in mils per year, A and k are constants, and d is the diameter of the wire in mils. This equation is purely empirical and as the experiments were not specifically undertaken to investigate the effect of diameter, insufficient results are available to study this relationship in detail. With this reservation, as a first approximation the value of the exponent k may be taken as the same for all materials, the differences in their observed resistance to corrosion being expressed by variations in the value of the constant A.

Curves showing the relationship deduced in this manner between the diameter of the wire and the rate of corrosion for ordinary mild steel X and for the chromium–copper steel N, are reproduced in Fig. 3. The equation used to calculate the values for material X was $t = 43{\cdot}45d^{-0{\cdot}4096}$; in the case of the chromium–copper steel N, which is twice as resistant to corrosion as ordinary mild steel X, the values of the ordinates have been halved.

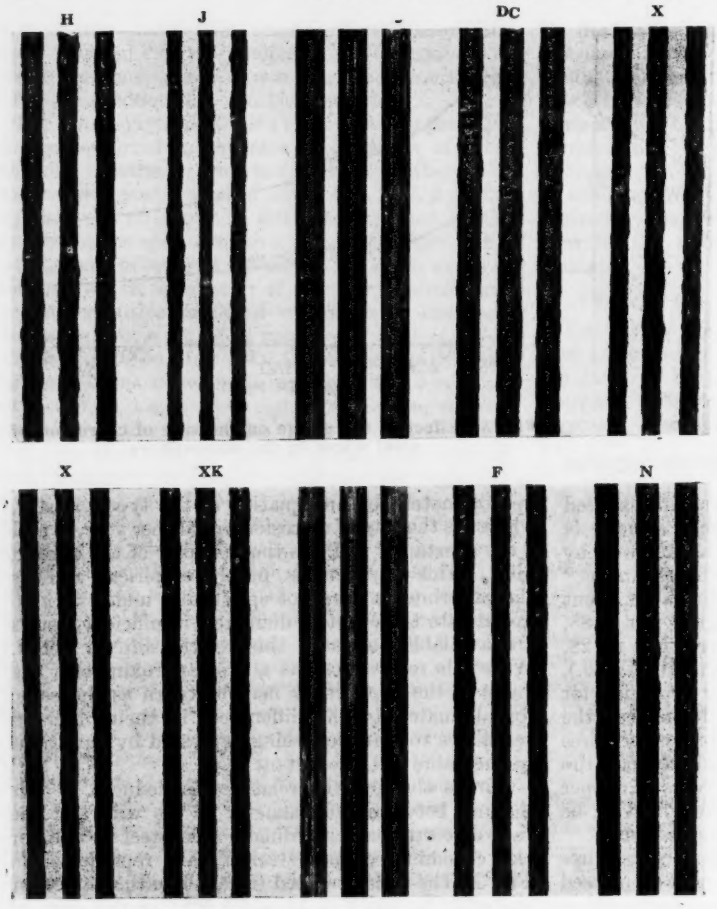
* *Transactions of the Faraday Society*, 1929, vol. 25, p. 477.

† *Journal of the Institute of Metals*, 1935, vol. 56, p. 100.

Table V

RELATIVE CORRODIBILITIES OF DIFFERENT FERROUS MATERIALS IN AN INDUSTRIAL ATMOSPHERE

Material		Relative Corrodibility (Mild Steel = 100)			
		Wire Tests at Sheffield University	Loss-in-Weight Tests at Main Sheffield Corrosion Station		
Designation	Code Letter		10 Years' Exposure	10 Years' Exposure	5 Years' Exposure
Chromium–copper steels	N only	47	...	35	39
	L, M, N	49	...	46	...
Copper-bearing Staffordshire wrought iron	DB, DD	53	...	...	...
Copper-bearing mild steel	O, Y, ZK	60	81	77	...
Staffordshire wrought iron	D, DA, DC	65	76	...	...
1% Chromium steel	K	73	...	49	...
Rail steel	F	84	...	...	...
Mild steel (Si 0·10%)	XK	93	...	89	...
Ordinary mild steel	X, X2	100	100	100	100
Aston-Byers iron	H	101	...	...	106
Ingot iron	E	114	106	...	...
Swedish wrought iron	J	121	143	...	...



Top Row		Dia, mils.	Bottom Row		Dia, mils.
H	Aston-Byers iron ..	160	X	Mild steel	155
J	Swedish wrought iron	124	XK	Mild steel (Si 0·10%) ..	165
—	Unexposed blanks ..	238	—	Unexposed blanks ..	238
DC	Staffordshire wrought iron	202	F	Rail steel	177
			N	Chromium-copper steel	200
X	Mild steel	155			

Fig. 4—Appearance of 3½-S.W.G. wires after 10 years' exposure at Sheffield University

COMPARISON OF THE DIFFERENT MATERIALS

In general, the results of the present wire tests are in good agreement with those of previous loss-in-weight tests on massive specimens. This is evident from Table V, in which the relative corrodibilities of the materials deduced from these tests on wires are compared with similar figures calculated from loss-in-weight tests on 15 in × 10 in × ⅜-in specimens at the main Sheffield corrosion station. It should be explained that the figures given in Table V for the wire tests have been derived from the results shown in Table III by expressing the extent of corrosion of each material or group of materials as a percentage of that for ordinary mild steel X or X2 or, in one case where no specimens of mild steel occurred in the set, in terms of the figure for Staffordshire wrought iron DA, taken as 65%. Figures have been calculated for each set of results shown in Table III and the values given in Table V are averages of these, *e.g.*, they include all gauges and periods of exposure and thus represent an overall average of the experimental results.

One or two differences between the results of the wire tests and of the loss-in-weight tests will be noted in Table V ; for instance, 1% chromium steel K has behaved less well in the wire tests than in the loss-in-weight tests. In the main, however, the ranking orders of the materials as regards resistance to corrosion are substantially the same. The results of the wire tests may be summarized by the statement that the chromium–copper steels are about twice as resistant to atmospheric corrosion as ordinary mild steel and that copper-bearing Swedish wrought iron is not greatly inferior to them. Unalloyed Staffordshire wrought iron is nearly as good as copper-bearing mild steel ; both these materials and also the 1% chromium steel are some 30–40% more resistant than ordinary mild steel. Aston-Byers iron and ingot iron are slightly inferior to mild steel, and Swedish iron markedly so.

It will be noted that the addition of 0·10% of silicon to the semi-killed mild steel XK has reduced corrosion by about 7% as compared with ordinary steel. Rail steel with a carbon content of 0·55% and manganese content of 0·61% is more resistant by 15% than ordinary mild steel. Although the former material has not been included in any of the main loss-in-weight tests so far, confirmation of this result is furnished by some subsidiary tests on specimens of ⅛-in plate conducted at Birmingham and at Farnborough.* In these tests, the losses in weight of the rail-steel specimens were observed to be 83% and 82%, respectively, of the corresponding losses for ordinary mild steel.

It should be added that some of the Staffordshire wrought irons tested were prepared in a special manner. In their cases, the billets from which the wire rods were rolled were piled in such a way as to produce a regular annular arrangement of the slag and scale layers.† The experimental results failed to show any appreciable difference between the two materials in question, DB and DD, and the corresponding wires rolled from normal piles of the same material DA and DC.

* Fourth Report of the Corrosion Committee : *The Iron and Steel Institute*, 1936, *Special Report No.* 13, pp. 201 and 206.

† *See* Third Report of the Corrosion Committee, *loc. cit.*, p. 188.

Some of the conclusions drawn in this section regarding the relative resistance of the different materials to atmospheric corrosion are illustrated by the photographs reproduced in Fig. 4.

CONSIDERATION OF THE DECREASE-IN-BREAKING-LOAD METHOD AS A MEANS OF DETERMINING ATMOSPHERIC CORROSION

In common with other experimental methods for determining corrosion, the decrease-in-breaking-load method has certain advantages and certain disadvantages. For example, the preparation of materials in the form of wire is less simple than when rolled plates or sections are used for the test specimen, as another works operation is involved; moreover, a tensile-testing machine, which is less common and more expensive than a balance, is needed to make the determinations. On the other hand, once the specimens have been prepared and the necessary testing equipment obtained, there are considerable advantages attached to the decrease-in-breaking-load method as regards ease and speed of testing; thus, the total weight of the specimens to be dealt with is much less than in the case of loss-in-weight tests on plates, and it is unnecessary to remove the rust from the specimens after exposure, which is a tedious and time-consuming process.

It is not, however, the purpose of the present section to discuss these features of experimental technique, but rather to consider the decrease in breaking-load method as applied to wires, from the point of view of its accuracy. It has already been concluded from Table V that the method results in classifying different ferrous materials in order of corrodibility with an accuracy of the same magnitude as that with which this order can be established from one test series to another. It remains, therefore, to consider the experimental accuracy of the method itself.

The problem has been approached by comparing the results of the present tests on the wires at Sheffield University with those of all the loss-in-weight tests so far conducted on 15 in × 10 in × $\frac{3}{8}$-in plates at the Committee's main atmospheric-exposure station at Sheffield, where the corrosive conditions are essentially of the same type. It is difficult to present an exact mathematical index of the experimental error when the number of similar specimens exposed in a single set is small, but it is thought that the following treatment of the subject is adequate for the present purpose :

(1) *Loss-in-Weight Tests*—These tests are made on duplicate specimens. The value of

$$\Delta_w = 100(a - b)/(a + b)$$

where a and b are the losses in weight of the individual specimens of each pair, has been taken as an index of the experimental error of each determination.

(2) *Decrease-in-Breaking-Load Tests*—In this case, the breaking loads of six corroded pieces of wire are compared with those of six similar blanks. The standard deviations σ_E and σ_B have been calculated

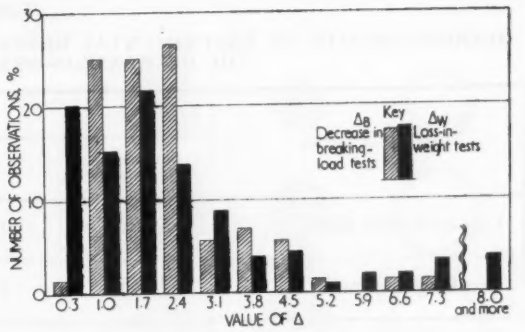


Fig. 5—Reproducibility of atmospheric-corrosion tests by the loss-in-weight and decrease-in-breaking-load methods

for each set of six and from these the standard deviation $\sigma_{B/E}$† of the decrease in breaking load, $B_B - B_E$, due to corrosion, B_B and B_E being, respectively, the average breaking load of the blanks and of the exposed wires.

The experimental error of each determination has been taken as :

$$\Delta_b = \frac{\frac{1}{2}\sigma_{B/E}}{100(B_B - B_E)}\ddagger$$

Altogether 204 values of Δ_w and 72 values of Δ_b are available. The distribution of these values is indicated graphically in Fig. 5, and the essential features of this distribution are given in Table VI.

It can be deduced from these figures, that the average value for Δ_w is $2{\cdot}46 \pm 0{\cdot}27$, with a probability of $0{\cdot}9$, as compared with an average value for Δ_b of $2{\cdot}26 \pm 0{\cdot}26$, with the same probability.

It would seem, therefore, that the sensitiveness and accuracy of determinations of corrosion by the decrease-in-breaking-load method are of approximately the same order as those of loss-in-weight determinations, at least when the tests are made in highly corrosive atmospheres. It is possible that for tests in less corrosive atmospheres, where the changes due

† $\sigma_{B/E} = \left(\sigma_B^2 + \sigma_E^2\right)^{\frac{1}{2}}$

‡ This is approximately correct for small values of Δ_b.

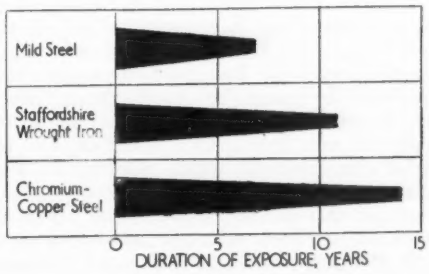


Fig. 6—Wastage through rusting of 10-S.W.G. (0·128-in. dia.) wires of various ferrous materials exposed in an industrial atmosphere

Table VI

REPRODUCIBILITY OF EXPERIMENTAL RESULTS BY THE LOSS-IN-WEIGHT METHOD AND BY THE DECREASE-IN-BREAKING-LOAD METHOD

Method of Testing	Distribution of Δw or Δb*				
	Number of Observations	$\bar{x}$	σ	Probability of 0·9	Probability of 0·99
Loss-in-weight tests	204	2·458	2·300	0·267	0·418
Breaking-load tests	72	2·264	1·293	0·256	0·401

* An explanation of these symbols is given on p. 283

to corrosion were relatively small, other considerations would come into play.

PRACTICAL CONCLUSIONS

POSSIBLE ECONOMIES RESULTING FROM THE USE OF LOW-ALLOY STEELS FOR THE PRODUCTION OF VARIOUS WIRES

It is fair to state that full use is not yet made in Great Britain of the practical advantages to be gained by the substitution for ordinary mild steel of low-alloy steels with increased resistance to atmospheric corrosion. These advantages are most pronounced in cases where the steel is used in the form of light-gauge components such as sheets and wires. An attempt will therefore be made in this section to set out as clearly as possible the degree of the economies in the consumption of material that might accrue from the use of low-alloy steels, instead of ordinary mild steel, for the manufacture of wire.

The problem can be approached from two angles, namely :

(1) What increase in life is to be expected from the substitution of more resistant materials for mild steel when the gauge of the wire is kept constant ?

(2) What reduction in gauge for a given life, in years, when exposed to atmospheric corrosion is rendered possible by this substitution ?

EXTENDED LIFE RESULTING FROM THE SUBSTITUTION OF LOW-ALLOY STEELS OR WROUGHT IRON FOR ORDINARY MILD-STEEL WIRE

The increase in life resulting from the use of more corrosion-resistant materials instead of mild steel will vary somewhat with the gauge of the wire and the conditions of exposure. For practical purposes it may be illustrated by means of the diagrams shown in Fig. 6. These depict the progressive wastages of wires originally 128 mils in dia (10 S.W.G.) exposed to an industrial atmosphere in which mild steel corrodes at the rate of 6 mils/year, *i.e.*, the conditions of exposure of the present experiments. The three materials selected for purposes of illustration are mild steel, Staffordshire wrought iron, and chromium–copper steel.

It will be seen that the life of the ordinary mild-steel wire is appreciably less than that of the Staffordshire wrought iron and that this life is more than doubled when chromium–copper steel is used.

PERMISSIBLE REDUCTION IN GAUGE FOR A GIVEN LIFE IN YEARS RESULTING FROM THE SUBSTITUTION OF LOW-ALLOY STEEL WIRE FOR ORDINARY MILD-STEEL WIRE

The problem to be solved under this heading may be enunciated as follows :

It is desired that after a period of n years' exposure to the atmosphere, a wire shall retain a breaking load of B lb. What gauges of ordinary mild-steel wire and of low-alloy steel wire, respectively, should be used ?

The solution is complicated by three factors :

The low-alloy steel will have a higher tensile strength than the ordinary mild steel

In both cases the tensile strength will be affected by the degree of reduction necessary to produce the selected gauge from the original wire rod

The rate of corrosion varies with the gauge of the wire (*see* p. 280)

The solution is also affected by the corrosiveness of the atmosphere to which the wires are exposed. For simplicity, therefore, the mathematical treatment will be limited to the concrete case of the atmosphere of Sheffield University, in which these experiments have been conducted, and to an exposure period of 10 years. Further, only two materials will be considered, namely, ordinary mild steel and chromium–copper steel. The corrosion of the latter will be assumed to be 50% of that of the mild-steel wire of the same diameter which, as will be seen from Table III, is a conservative estimate. The effect of variations in the tensile strength with gauge can be allowed for by multiplying the known breaking load for the 3½-S.W.G. (242 mils) wires by factors representing the hardening due to cold work. In the present case the factors used vary from 0·82 for wire 300 mils in dia to 1·43 for wire 100 mils in dia.* The variation

* These factors are based on determinations of the breaking load made at intermediate gauges during the production of the mild-steel wire that was tested. This material was rolled to 2-S.W.G. wire rod and then drawn down to 10 S.W.G. (128 mils), passing through 3½-, 5½-, 7-, and 8½-S.W.G. holes. Admittedly, for some purposes it might be necessary to soften the wires after drawing, but such considerations are of secondary importance in relation to the general point at issue in the present discussion.

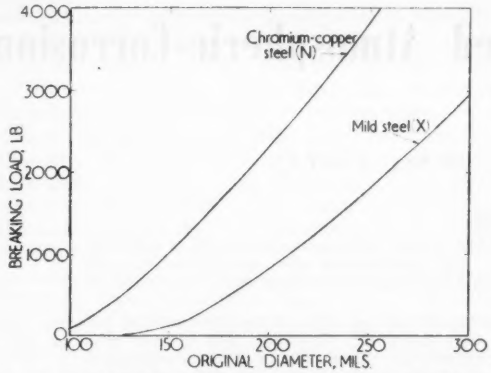


Fig. 7—Residual breaking loads of wires of mild steel and chromium–copper steel after 10 years' exposure in an industrial atmosphere

of corrosion rate with wire diameter can be allowed for by reference to the data given in Fig. 3.

The results of calculations made in this way, with the details of which it is unnecessary to burden the reader, are given in Fig. 7. This shows the calculated residual breaking loads, in pounds, of wires of mild steel and of chromium–copper steel, respectively, of initial diameters ranging from 100 to 300 mils after 10 years' exposure at Sheffield University. As the wires break some little time before the theoretical reduction to zero diameter,* it may be deduced that in order to withstand corrosion for the whole period of 10 years, the original diameter of the wires should be about 160 mils at least, in the case of ordinary mild steel, or 110 mils in that of chromium–copper steel.

Figure 8 represents in a diagrammatic manner the answers to the specific question : what diameters of mild-steel wire, on the one hand, and of chromium copper steel, on the other, should be exposed now to ensure that after 10 years' corrosion in the atmosphere studied both wires shall have breaking loads of 500, 1000, or 2000 lb ? It will be seen that the advantage lies with the chromium–copper steel to a pronounced degree and that the economy in the weight of steel used resulting from the substitution of this low-alloy steel for mild steel is of the order of 50%.

GENERAL CONCLUSIONS

Corrosion is not the only factor governing the choice of materials for the manufacture of iron or steel wires. Nevertheless the author would venture to draw attention to the points made above and to suggest that, in view of the undoubted economies from the point of view of corrosion resistance to be derived from the substitution of low-alloy steels for ordinary steel, such materials might with advantage be more widely adopted for the manufacture of wires, where other circumstances permit.

* In practice it has been found that a residual diameter of 40 mils, corresponding to a breaking load of about 175 lb for mild steel, is a reasonable allowance for this factor.

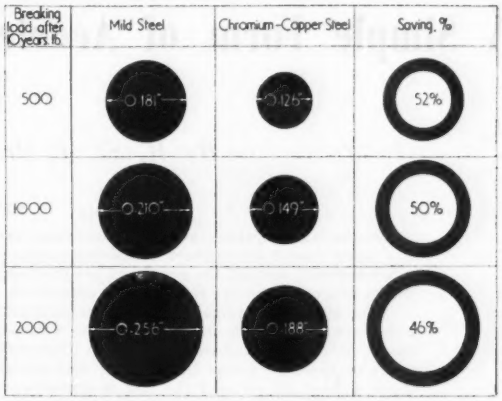


Fig. 8—Initial diameters of wires of mild steel and of chromium–copper steel necessary to ensure given residual breaking loads after 10 years' exposure in an industrial atmosphere

These economies would result both from the saving in materials and from the reduced costs of replacement. For example, the production of wire rod in the United Kingdom in 1944 was about 800,000 tons. If all of this material had been destined for use in the open in the bare unprotected condition (admittedly an assumption that is wide of the mark) an economy in the consumption of steel of up to 400,000 tons, for equal service, would have been achieved by making all this wire in, say, chromium–copper steel. The cost of the alloying elements, some of which might be in short supply would, of course, have to be set off against this saving. In all probability, however, the maximum economies resulting from the judicious use of low-alloy steel wires would be achieved by maintaining the existing gauges and thus reaping the benefits of the increased life of the fabricated articles, for the cost of the materials themselves is but a small fraction of the expense involved in replacement at unnecessarily short intervals.

As a practical example of this, a galvanized wire link fence of good commercial quality erected in 1939 round the author's garden in the suburbs of Birmingham is now beginning to fail, several strands having rusted through (1948). Had this wire been of chromium–copper steel, an increase in the life of the fence of up to 5 years might reasonably have been expected.

Acknowledgments

It is the author's pleasant duty to acknowledge that the mechanical testing involved in these investigations was carried out in the Research Department of Messrs. Bruntons (Musselburgh), Ltd., through the kind arrangement of Mr. A. T. Adam, to whom, on behalf of the Atmospheric Corrosion Sub-Committee, and on his own account, he wishes to express thanks for this helpful collaboration rendered over a long period of years.

A Simple Form of Accelerated Atmospheric-Corrosion Test

By R. St. J. Preston, M.Sc., F.R.I.C.

SYNOPSIS

A simple accelerated atmospheric-corrosion test is described in which specimens are subjected to corrosion in a warm humid atmosphere containing sulphur dioxide. The experimental work was carried out with steam-heated apparatus, since replaced by a thermostatically controlled electrically heated type. The apparatus can be easily constructed from readily procurable materials.

The effects of temperature and concentration of sulphur dioxide on rates of corrosion of bare and phosphated steel, with and without paint coverings, have been examined. Corrosion rates increase with rise in temperature and with increase in sulphur-dioxide concentration. In the case of bare steel, corrosion tends to approach a maximum at an initial concentration of sulphur dioxide in the underlying solution of about 0·02 g/100 ml, and the rate is approximately seven times that of steel exposed in the local urban atmosphere.

Pre-treatment by phosphating improves the corrosion resistance of painted steel, particularly when the paint coating is less than 0.5 mil thick. A thick phosphate coating, which does not conduct electricity and has therefore completely covered the basis steel, showed a resistance in outdoor exposure tests much superior to that of bare steel.

A method of determining the spread of rust by measurement of light reflection and effects of artificially damaging paint films are discussed.

A SIMPLE form of accelerated atmospheric-corrosion test (a condensation-type corrosion test) has been developed at the Chemical Research Laboratory in the course of researches on phosphate coatings on steel. It was originally designed for comparing the corrosion resistance of protective coatings of the paint type (priming paints) applied to steel surfaces with or without a phosphate pre-treatment, but preliminary experiments have suggested that it may also be suitable for the comparison of coatings regarded generally as more durable than simple paint systems, *e.g.*, metallic coatings. The experimental work reported in this paper, however, is confined to tests on plain and phosphated steel, with and without paint cover.

GENERAL FEATURES OF ACCELERATED TESTS

Practically all accelerated atmospheric-corrosion tests involve the exposure of specimens to atmospheres highly charged with moisture, at least for part of the time, and usually containing additional electrolytes in the form of salts or dilute acids. Corrosion occurs when the solution of electrolyte makes contact with the metal surface, and the rate of attack varies *ceteris paribus* with temperature.

Electrolytes used in accelerated atmospheric-corrosion testing are generally of two types, *viz.*, salts (mainly sodium chloride or sea salt) and mineral acids (mainly sulphuric acid). Although such tests may only have reference to marine and industrial atmospheres respectively, they are frequently used as general tests of corrodibility independently of the particular environment to which a material may be exposed in practice. This is particularly the case with the salt-spray type of test, which, in various forms, is perhaps more widely used than any other. A doubt may arise, however, when chloride salts are used for tests on materials which are to be used in industrial atmospheres, and conversely, in respect of sulphur-oxide acids for marine atmospheres, unless the limitations of the tests have been defined by previous experimental work ; it has been shown that corrosion rates may be widely different in the two types of atmosphere. In the case of iron and zinc, for example, the ratio of their rates of corrosion in an industrial atmosphere is approximately six times that in a marine atmosphere.[1] The results of laboratory tests are also influenced by the type of atmosphere. Figure 1 shows how steels, containing various proportions of copper, can be affected by a synthetic sea-water spray test in one case, and exposure to a

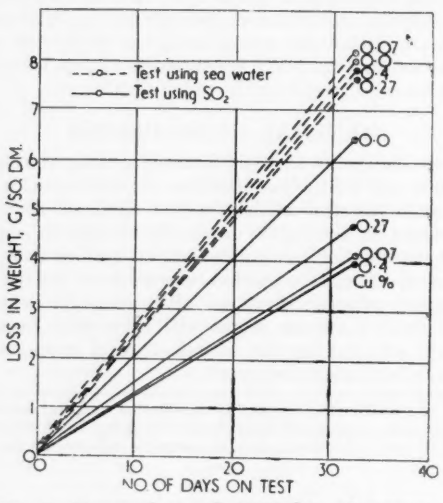


Fig. 1—Comparison of corrosion of copper steels under various conditions of test

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predominantly sulphurous atmosphere in the other. The superior corrosion resistance of the copper steels compared with that of the mild steel is only brought out by the sulphurous atmosphere, thus confirming the experience of atmospheric-exposure tests.

Humidity tests are also widely employed in assessing protective schemes, and are generally considered to show good correlation with results from atmospheric exposure ; the acceleration factor is low, however.[2] The condensation-type corrosion test can be used as a humidity test, and is less expensive than the standard humidity cabinet. As the apparatus was principally designed for comparing the corrosion resistance of materials intended for use in industrial types of atmosphere, without unduly prolonging the time of test, a sulphurous-type atmosphere has been adopted. Besides representing the main atmospheric constituent responsible for accelerating corrosion, sulphur dioxide can be used directly without the complication of spraying devices essential for salt or sulphuric-acid-spray-type tests.

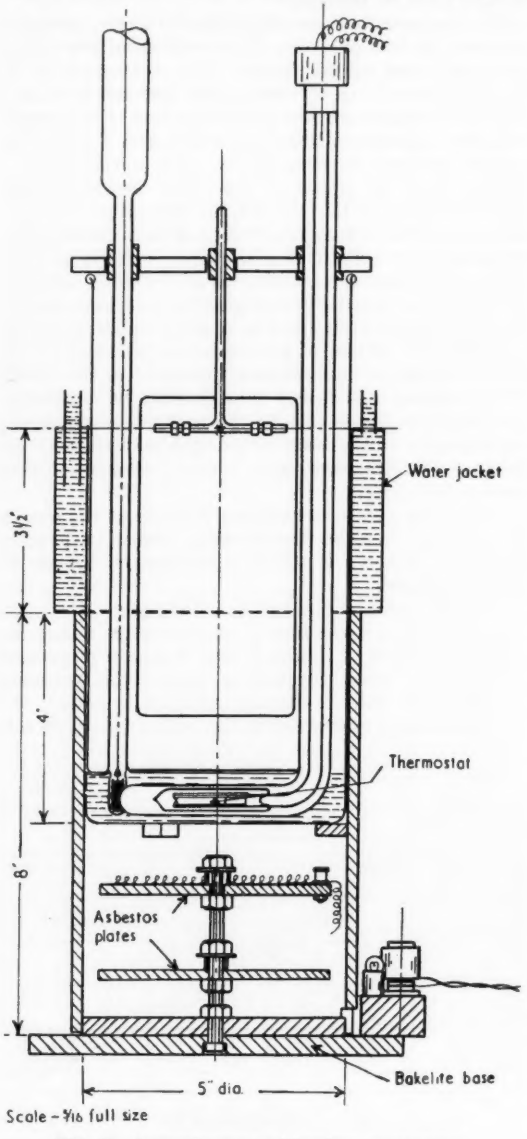

Fig. 2—Arrangement of beaker apparatus

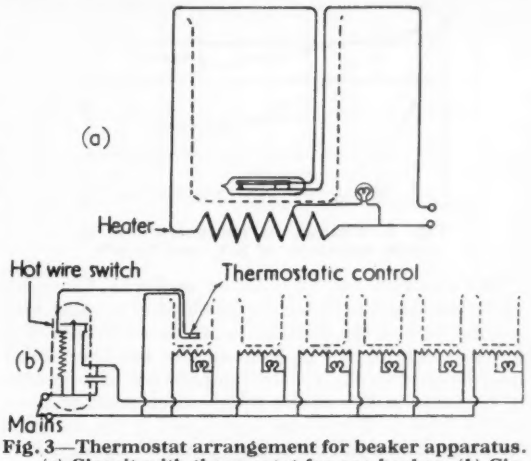

Fig. 3—Thermostat arrangement for beaker apparatus. (*a*) Circuit with thermostat for one beaker; (*b*) Circuit with one thermostat as master control

DESCRIPTION OF THE CONDENSATION-TYPE CORROSION APPARATUS

The apparatus consists mainly of a large beaker, the lower part of which is heated and the upper part cooled, thereby ensuring, in the presence of a small volume of water in the beaker, an atmosphere of 100% relative humidity. All the experimental work was carried out with this type of apparatus, which was heated by an external steam coil.

Although heating by saturated steam ensures reasonable constancy of temperatures, it has two disadvantages, *viz.*, loss of test time when the steam is cut off at night, and difficulty in controlling temperature except at the maximum. Even at the maximum temperature the inevitable differences between beakers and between steam coils require to be compensated to obtain the same temperature in each beaker. Steam heating has therefore been replaced in the later type of apparatus by a thermostatically controlled electrical element. A diagrammatic sketch of this apparatus is shown in Fig. 2, and Fig. 9 is a photograph of part of a bank of six. A 3-litre tall-form lipless beaker of high-resistance glass rests on three studs in an asbestos-cement tube of 5 in. dia. The heater element of 36 S.W.G. (0·0076 in. dia) nickel–chrome wire giving 75 W (720 ohms at 230 V) is fixed on an asbestos base about 1½ in below the beaker, but is adjustable in height ; the element is connected in series with a simple bi-metallic-strip type of thermostat sealed in an evacuated glass tube. To avoid contact of its leads with the corrosive solution in the beaker, the thermostat is enclosed in a glass tube, bent as shown in Fig. 2, so that it lies across the bottom of the beaker and below the surface of the solution. In this way the temperature of the solution is maintained constant within a range of about 2–3° C.

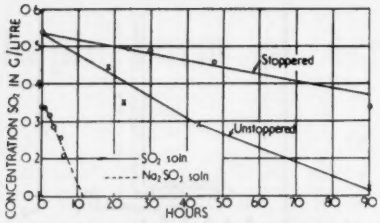

Fig. 4—Change in concentrations of stock solutions of SO_2 and Na_2SO_3

The electrical circuit is shown in Fig. 3, the small $3\frac{1}{2}$-V flash-lamp bulb being connected in parallel with a small part of the element to act as a tell-tale. The lower sketch (*b*) in Fig. 3 shows how one thermostat may be used to control the temperature of a number of beakers ; in this case a relay switch must be used, as the type of thermostat mentioned is not designed to carry a current exceeding 1 amp. By means of a suitable relay switch a considerable number of beakers can be controlled by one master thermostat. Variations in temperature between beakers, owing to slight differences in element windings, thickness of the glass of the beakers, etc., can be practically eliminated by raising or lowering the element, for which provision is made (*cf.* Fig. 2) or by adjusting the length of the heater elements.

The upper part of the beaker is cooled by means of a " compo " cooling coil, or by an annular condenser (*e.g.*, of brass as shown in Figs. 2 and 9). The cooling arrangement maintains atmospheric saturation in the upper part of the beaker at a reasonably constant temperature. At higher working temperatures the direct loss of heat to the atmosphere is such that the cooling jacket can be dispensed with.

The lid of the beaker is made from $\frac{1}{4}$-in unplasticized Perspex and is provided with holes for thermometers, tap funnels, specimen support (approximately $\frac{5}{8}$ in. dia), and thermostat tube (approximately $\frac{3}{4}$ in. dia). One hole is at the centre, the others at approximately $1\frac{7}{8}$-in centres from the centre. The lid rests on a seating made from thin-walled rubber tubing, split along its length and clipped at the ends.

METHOD OF OPERATION

The size of test specimen is not critical ; specimens ranging from 4 in × 2 in to 6 in × 4 in* have been used in the course of experimental work, but a rather more uniform rate of corrosion over the surface is obtained with the smaller specimens, and a size not greater than 6 in × 3 in is preferred. The specimens are suspended from a glass support at a distance of approximately 1 in from the centre ; in the case of 6-in × 4-in specimens the distance from the centre is reduced to about $\frac{3}{4}$ in to avoid too-close proximity of the edges to the beaker wall. There is no evidence that the position of the specimens has any marked effect on their corrosion rate, nor would such effects be expected in view of the saturated condition of the vapour space and its reasonable uniformity in temperature.

The use of the apparatus as a simple small-scale humidity test requires no explanation. For the more corrosive atmospheres provided by sulphur dioxide, either sodium sulphite and acid, or a straight solution of sulphur dioxide in water may be used. In early tests sodium sulphite was used, but experience has shown that, whereas a sulphite solution deteriorates considerably in one day, a solution of sulphur dioxide in water in a stoppered vessel alters only slightly (see Fig. 4). Part of the change in sulphur-dioxide concentration in a typical stock solution shown in Fig. 4 may be explained by temperature variations.

To prepare the solution, water is saturated at a known temperature with sulphur dioxide, the concentration being read from a graph (Fig. 5), the data for which were obtained by calculation from experimental work of Hudson.[3]

The concentrated solution is diluted to the strength required for test purposes. For a volume of 300 ml, as normally used in the beaker, the concentration of sulphur dioxide is $CV/300$ g per 100 ml of water, where C represents the concentration of the stock solution in grammes/100 ml of water, and V ml is the volume of stock solution taken. The initial concentration used in most of the tests described was approximately 0·015 g of SO_2 per 100 ml of solution, the test solution being renewed each day. Subsequent work has shown that it is advantageous and more convenient to make three additions of the stock solution of sulphur dioxide daily, changing the solution once per week ; in practice 10 ml of a solution containing 0·45 g of SO_2 per 100 ml of solution are added every four hours during the day. Some adjustment of the initial concentration of sulphur dioxide may be necessary, according to the nature of the material under test ; for example, in the tests on phosphated steel without paint cover, described later, a much weaker solution was satisfactory.

If it is desired to use sodium sulphite as the source of sulphur dioxide, the solution must be freshly prepared, or the salt added to the beaker directly in the solid form.

The operation of the test is as follows :

Specimens up to four in number when 2 in wide, or two of 6 in × 3 in or 6 in × 4 in, are suspended from the glass supporting arms ; the requisite volume of sulphur-dioxide solution is added, the total amount of solution in the beaker being 300 ml ;

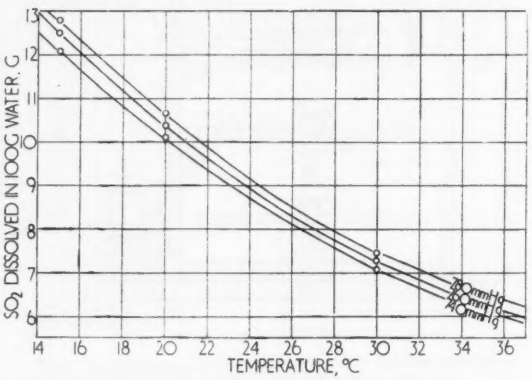

Fig. 5—Solubility of SO_2 in water

* The size adopted in B.S.S. 1391 : 1947.

heat is applied and a rapid flow of cooling water passed through the jacket. With steam-coil heating the temperature of the solution rises to 65° C and remains constant while the steam is on; with the electrically heated apparatus a wide range of temperatures is available, but to ensure adequate condensation on the specimens a temperature not less than 45° C seems desirable.

The duration of test periods and assessment of corrosion vary with the type of material undergoing test and degree of acceleration. In the case of single coats of paint on steel, plain and phosphated, differences in resistance to corrosion are shown within a week, even with the more dilute sulphur-dioxide solutions. Two methods of assessment of corrosion are available: (*a*) gain in weight due to formation of corrosion product, and (*b*) visual inspection; the latter made with or without the aid of a light-reflection meter. In the case of unprotected metals, the determination of the loss in weight on removal of corrosion products affords a more reliable criterion, particularly when the corrosion is heavy.

APPLICATIONS OF THE CONDENSATION-TYPE CORROSION TEST

The experiments carried out with the apparatus include tests on bare and painted steel with and without surface pre-treatment by phosphating processes. Corrosion has been assessed by determining losses in weight in the case of unpainted steel, and gains in weight in the case of painted steel, supplemented by measurement of changes in light reflection. The light-reflection meter comprises an optical integrating sphere provided with apertures for light source, specimen, and photo-electric cell. Light reflected from the specimen is directed into the cell and registers on a galvanometer.

TESTS ON MILD STEEL

Tests on mild steel have been directed towards finding the effect of temperature as an accelerative factor in stimulating corrosion in a humid atmosphere, the degree of reproducibility of the test, and the influence of variation of sulphur-dioxide concentration in the humid atmosphere.

Table I

EFFECT OF TEMPERATURE ON THE CORROSION RATE OF MILD STEEL AT 100% RELATIVE HUMIDITY

Mean Temp., °C	Loss in mg per 100 g of Steel Sheet				Average	Standard Deviation
	Beaker Number					
	1	2	4	5		
23	22	16	25	19	21	4
28	67	69	72	76	71	4
31	106	110	107	95	105	7
36	206	221	187	206	205	14
45	409	449	449	441	437	19
Average	202	216	210	209	209	6

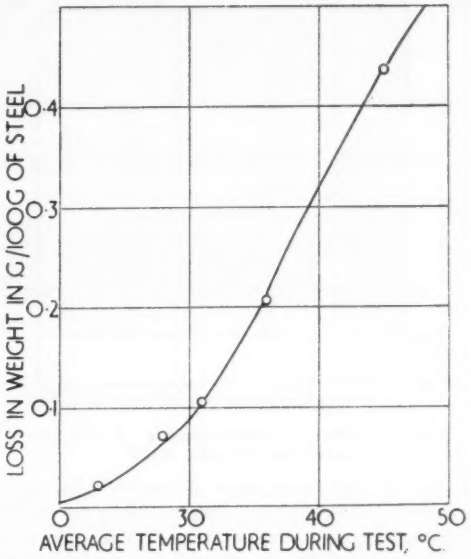

Fig. 6—Effect of temperature on corrosion rate

Corrosion of Mild Steel in a Humid Atmosphere

A set of 120 specimens, size 6 in × 2 in, cut from 20-gauge pickled mild-steel sheet, was degreased by swabbing with trichlorethylene, followed by a vapour bath in the same solvent. They were exposed for one day in 5 sets of 24 in 6 beakers (4 per beaker) to humid atmospheres at five different temperatures. The variation in temperature was obtained by passing steam through the heater coils for various times and recording the temperature in the vapour during the day, calculating the average temperature from an integration of the temperature-time curve. The vapour temperature was taken at a point approximately 3 in from the top of the beaker and about 1⅞in from the centre, but owing to the presence of convection currents the position of the thermometer is not critical, the variation in temperature in the vapour space being comparatively small (3–4° C between top and bottom of the vapour space). The results are not claimed to represent the effect of temperature with any great precision, because of the absence of thermostatic control, and further experiments are in progress with this objective. The losses in weight of steel, after removal of the rust by solution in inhibited sulphuric acid, are given in Table I and are plotted in Fig. 6. Between 35° and 45° C the loss of steel by corrosion is approximately 0·025 g per 100 g of 20-gauge sheet per degree Centigrade.

Degree of Reproducibility of the Test

Statistical analysis showed that the results from beakers 3 and 6 were significantly higher than the mean, and as there was evidence of somewhat higher temperatures in these beakers they have been omitted from the summarized results in Table I. The standard deviation of an individual result is approximately 10% of the average over the whole temperature range tested, and approximately 5% per set of four specimens in a beaker. It will be noted from Table I that

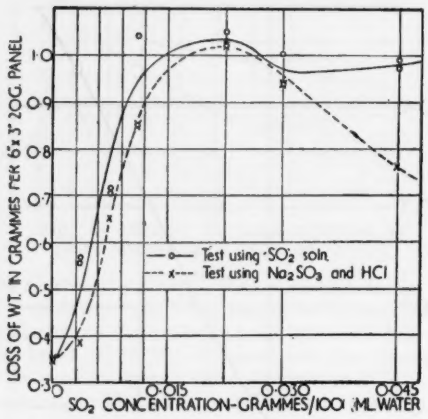

Fig. 7—Effect of concentration of SO_2 on corrosion of mild steel

accuracy of the experiment decreases with rise in temperature, as would be expected from the method of controlling the temperature. The degree of reproducibility of results should prove to be better in the thermostatically controlled apparatus.

The possibility of the existence of a maximum corrosion rate under atmospheric conditions will be the subject of further experiment. Such a maximum has been reported by Heyn and Bauer[4] as being between 60° and 80° C for conditions of immersed corrosion.

The results of the experiments show that an appreciable increase in corrosion rate may be achieved by raising the temperature of test above that of the atmosphere. The change in rate of corrosion over a range of temperatures is associated with availability of oxygen in a system freely open to the atmosphere. For example, at the temperature of 100° C (760 mm atmospheric pressure) there is theoretically no free oxygen in the system, and the reaction between iron and water vapour to produce the lower oxide takes place[5]. The presence of the film of oxide retards the reaction (*loc. cit.*), so it would appear that at temperatures in the region of 100° C there is a possibility, not only of a reduced rate of corrosion, but also a change in the nature of the corrosion product.

In the type of apparatus heated by steam coils the temperature of the vapour does not exceed 45° C, which gives a reasonable acceleration of corrosion rate over that at atmospheric temperature. For most of the experiments to be described the temperature of the vapour was approximately 45° C.

Tests on Mild Steel in Humid Conditions in Presence of Sulphur Dioxide

A considerable increase in the rate of corrosion of mild steel is achieved in the presence of humid atmosphere containing a small amount of sulphur dioxide[6]. Experiments were carried out on 6-in × 3-in specimens to determine the effect of varying the concentration of the gas on the corrosion rate of mild steel. Various amounts of sodium-sulphite solution with equivalent amounts of hydrochloric acid were added to the beakers, the volumes being made up to 300 ml in each case. The experiments were repeated using an aqueous solution of sulphur dioxide instead of sulphite. The range covered in both series of tests was from 0 to 0·045 g of SO_2 per 100 ml of solution added at the beginning of the tests, the relative concentrations of SO_2 in the gaseous and liquid phases being approximately in the ratio of 2/1 at the working temperature. The effect of varying the initial concentration of SO_2 solution is shown in Fig. 7. At concentrations of SO_2 exceeding approximately 0·020%, the corrosion rate tends to decrease, the steel becoming covered with a black corrosion product. The highest rate of corrosion shown in Fig. 7 is approximately three times that occurring in a humid atmosphere without sulphur dioxide, and about seven times that of steel exposed outdoors in an urban atmosphere in winter.

TESTS ON PAINTED STEEL*

The effect of such factors as variation of sulphur-dioxide concentration, thickness, and type of paint film, and pre-treatment of steel by phosphating, have been examined in the course of experimental work with the apparatus.

Influence of Paint Thickness and Phosphate Pre-Treatment on Corrosion Resistance

A number of 4-in × 3-in 20-gauge steel panels, half of which were phosphated in a manganese-phosphate-type bath, were coated with various thicknesses of CS2249 paint (off-white stoving primer). One side of each panel was damaged by applying scratch lines in directions parallel to the sides of the panels and separated by ¼-in spacings. It was thought that this form of damage which is, in effect, a multiplication of the standard scratch of B.S.S. 1391 : 1947, would magnify weight increases due to the spreading of rust at the damaged areas and thus supplement this method of measurement, which, in view of the variations in the spread from a scratch line, may be subject to some inaccuracy.

A concentration of 0·015 g per 100 ml of sulphur dioxide was used for the test, the 300 ml of solution being renewed daily for ten days, and the progress of rusting was determined by means of the light-reflection meter and weight increments. The results of light-reflection measurements of typical specimens are summarized in Table II.

* Throughout the paper, painted steel refers to coatings applied by dipping and finished in a stoving oven.

Table II

CORROSION OF PLAIN AND PHOSPHATED STEEL COATED WITH VARIOUS THICKNESSES OF PAINT

Average Paint Thickness, mil, approx.	Change of Light Reflection (Galvanometer Divisions)					
	Undamaged Surface				Damaged Surface	
	Phosphated		Plain		Phosphated	Plain
	Loss	Gain	Loss	Gain	Loss	Loss
0·25	2	...	14	...	17	23
0·4	0·5	...	9	...	15	23
0·8–0·9	...	1·5	...	4	15	15
1·5	...	6	...	8	14	14

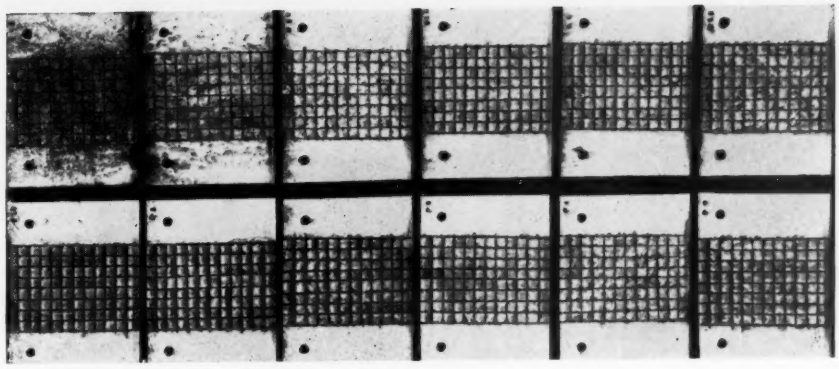

Fig. 8—Fronts of specimens showing effects of phosphating and paint thickness

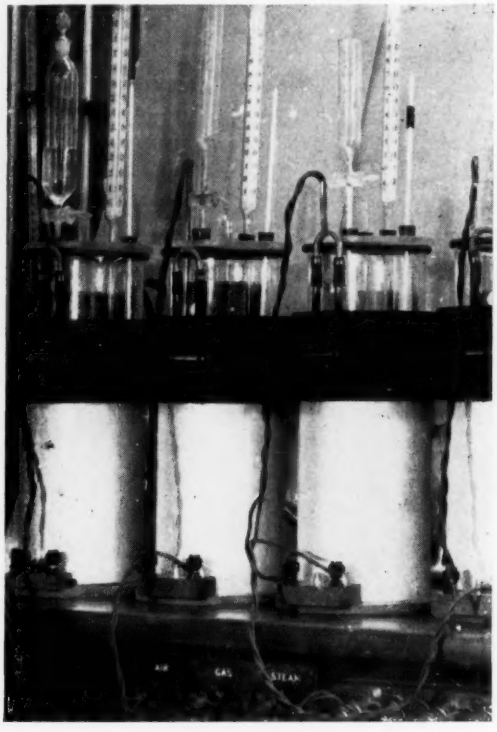

Fig. 9—Thermostatically controlled apparatus

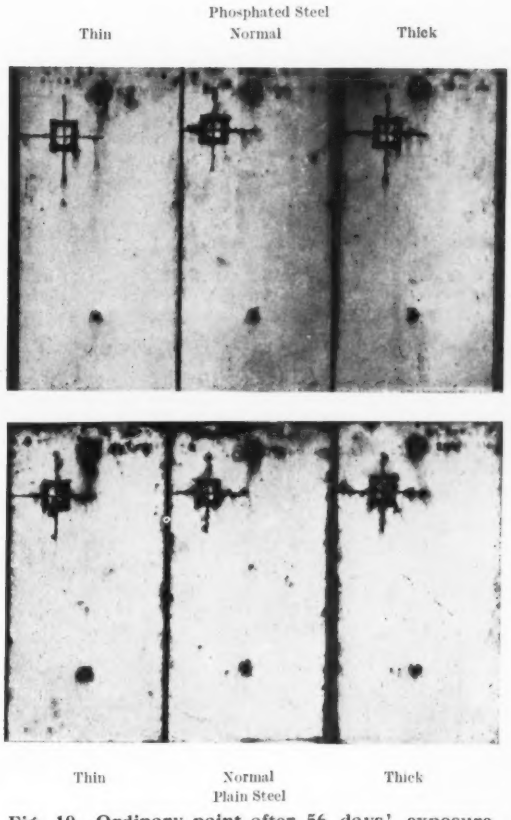

Fig. 10—Ordinary paint after 56 days' exposure to humid atmosphere

[*Preston*

[*To face p.* 290

Fig. 11—Ordinary paint after 7 days' exposure above solution containing 0·014 g. of SO_2 per 100 ml.

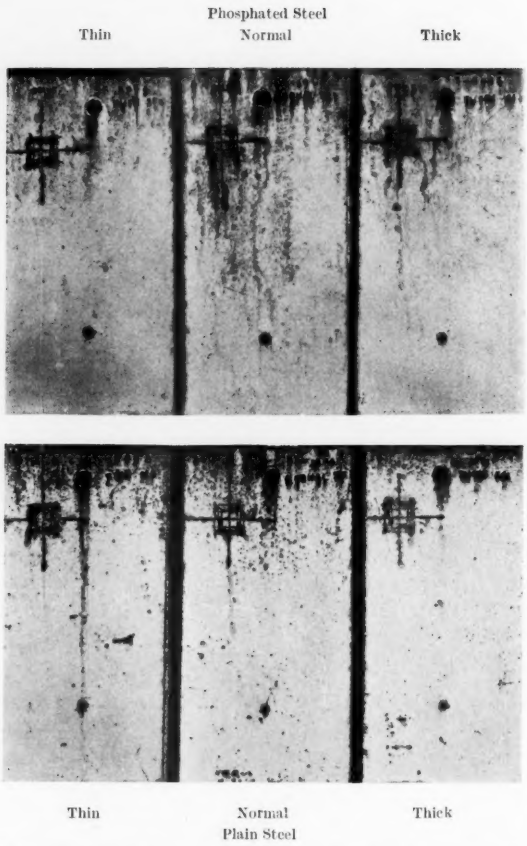

Fig. 12—Inhibitive paint after 7 days' exposure above solution containing 0·014 g. of SO_2 per 100 ml.

The total gain in weight at the end of the test ranged from 0·02 to 0·07 g in the case of the phosphated steel, and from 0·08 to 0·13 g in the case of the specimens that had not been pre-treated, but there was no definite correlation between the weight increments and film thicknesses. This could be due to inevitable variations in widths and depths of the hand-inscribed scratch lines causing variations in the extent of corrosion at these bare areas.

Photographs of the fronts of twelve damaged-surface specimens at the conclusion of the test are shown in Fig. 8. In Table II, those phosphated

Table III

CORROSION RESULTS OF ORDINARY AND INHIBITIVE PAINTS ON PHOSPHATED AND PLAIN STEEL

SO_2 Concentration, g/100 ml	Pre-treatment	Type of Paint	Wt of Phosphate, g/sq.ft.	Wt of Paint on 6-in × 3-in Panel, g	Approx. Thickness of Paint, mil	Gain in wt on Corrosion, 6-in × 3-in Panel, g	Change in Light Reflection on Galvo Scale	
							Gain	Loss
0·014	None	CS2249	...	0·822	0·55	0·089	...	7·0
				0·872	0·57	0·062	...	17·6
				1·053	0·70	0·067	...	13·0
		Inhibitive	...	0·244	0·27	0·082	6·0	...
				0·260	0·29	0·086	3·0	...
				0·287	0·32	0·047	7·4	...
	Phosphated	CS2249	0·22	0·902	0·60	0·030	...	1·6
			0·31	0·895	0·60	0·022	...	3·0
			0·30	1·072	0·71	0·029	...	2·0
		Inhibitive	0·16	0·216	0·24	0·037	6·0	...
			0·24	0·277	0·31	0·041	7·0	...
			0·26	0·382	0·43	0·034	8·0	...
0·007	None	CS2249	...	0·796	0·53	0·044	3·4	...
				0·898	0·60	0·030	0·6	...
				0·979	0·65	0·031	3·6	...
		Inhibitive	...	0·238	0·27	0·053	2·4	...
				0·268	0·30	0·054	3·4	...
				0·314	0·35	0·048	5·4	...
	Phosphated	CS2249	0·25	0·894	0·60	0·010	5·0	...
			0·22	0·900	0·60	0·011	2·0	...
			0·32	1·147	0·76	0·012	...	2·5
		Inhibitive	0·24	0·231	0·26	0·057	3·0	...
			0·25	0·267	0·30	0·020	4·0	...
			0·29	0·324	0·37	0·018	5·0	...
None	None	CS2249	...	0·798	0·53	0·006 (0·029)*	8·4 (9·5)*	...
				0·900	0·60	0·002 (0·021)	7·0 (3·5)	...
				1·084	0·72	0·002 (0·004)	6·4 (1·5)	...
		Inhibitive	...	0·232	0·26	0·008 (0·031)	4·4 (10·5)	...
				0·256	0·29	0·005 (0·029)	4·4 (10·5)	...
				0·308	0·35	0·002 (0·012)	6·6 (12·5)	...
	Phosphated	CS2249	0·35	0·867	0·58	0·002 (0·003)	10·0 (4·5)	...
			0·23	0·923	0·66	0·001 (0·007)	4·0 ...	(3·5)
			0·25	1·160	0·77	0·001 (0·005)	6·0 ...	...
		Inhibitive	0·26	0·250	0·29	0·004 (0·013)	4·0 (7·0)	...
			0·22	0·254	0·29	0·003 (0·006)	5·0 (4·0)	...
			0·28	0·334	0·38	0·001 (0·003)	6·0 (6·0)	...

* Figures in brackets refer to 56-day tests

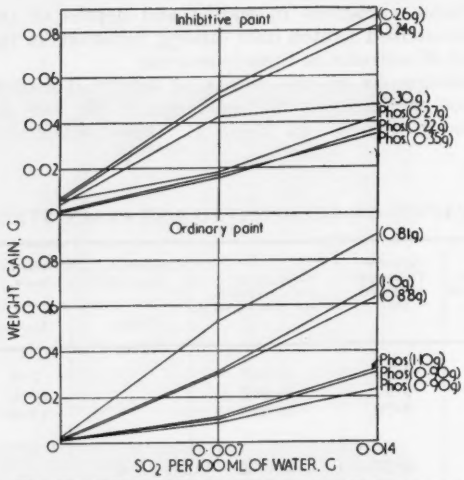

Fig. 13—Effect of SO_2 concentration (7 days' test)

specimens having the greater thicknesses of paint show gains in light reflection from the undamaged surfaces, indicating bleaching of the surfaces; any loss of reflectivity is due to rusting being insufficient to counterbalance this effect during the period of the exposure. The bleaching effect is, of course, completely masked on the damaged surfaces, where the spread of rust and rust stains are preponderant.

The results show that phosphate pre-treatment has a marked effect in reducing corrosion when the paint film is less than approximately $\frac{1}{2}$ mil thick. This is clearly seen in Fig. 8 in which the figure showing weights of paint in grammes may be taken to represent the approximate paint thicknesses in mils. It should be mentioned that although the phosphate coatings were of a coarse-grained type, they did not retain significantly greater amounts of paint than the plain steel when dipped in paint of the same viscosity, and the improvement in corrosion resistance resulting from phosphating is not due to retention of more paint by the phosphated surfaces.

Comparison of Ordinary Stoving Primer with an Inhibitive Primer

The primer denominated CS2249 is of the linseed-oil/copal-resin type, containing pigments that are not specifically inhibitive of corrosion. It was of interest therefore to compare its corrosion resistance with that of a paint of the corrosion-inhibitive type. This paint was comprised of a medium containing alkyd resin with a pigment containing zinc chromate. Stoved coatings of various thicknesses on phosphated and plain-steel panels of size 6 in × 3 in were subjected to three concentrations of corrosive atmosphere, corresponding to 0, 0·007 and 0·014 g of SO_2 per 100 ml of solution, for a period of seven days. The various paint-film thicknesses were obtained by diluting the stock paints with various amounts of thinner. In the case of the inhibitive primer it was not realized until the weights of the films were obtained, that the stock paint was apparently of lower viscosity than that of the CS2249 stock, and in consequence the films of inhibitive paints are much thinner than was anticipated. The paint thicknesses varied from approximately 0·5 to 0·7 mil in the case of the ordinary paint, and from approximately 0.25 to 0·4 mil in the case of the inhibitive paint.

Each painted panel was artificially damaged by a series of scratches through the paint film to form a chequer-board pattern, the size of the smallest square being approximately $\frac{1}{16}$ in (Figs. 10 to 12). The lower halves of the panels were damaged by means of a standard falling-weight impact machine.* The object in applying the chequer-board-pattern damage was to correlate, if possible, the protective value of the various films and pre-treatments with the rate of obliteration of the various areas of paint enclosed within the scratch lines. Changes in light reflection were measured at periods during the test, both on the undamaged and damaged areas of the panels, and weight changes were also recorded. The results of the tests are summarized in Table III, and typical specimens after test are shown in Figs. 10 to 12.

Owing to the small increases in weight of the panels exposed for seven days to a humid atmosphere without sulphur dioxide, the test time was extended for these to 56 days.

Figure 13 shows the effect of varying the sulphur-dioxide concentration on the rate of corrosion of the various specimens; Figures 14 and 15 show light-reflection changes on undamaged areas at the higher concentration of sulphur dioxide, and on damaged areas at the lower concentration, respectively.

The performance of the inhibitive paint is much superior to that of the ordinary paint as judged by light-reflection changes, but is somewhat inferior when judged by weight increases. The divergence is largely due to the more localized attack in the case of the inhibitive paint, which causes only a small change in light reflection due to rusting, the change being insufficient to counterbalance the bleaching of the paint in the course of the test. In the case of the ordinary paint, rust stains spread over the surface and effected a marked reduction in light reflectivity.

* As described in B.S.S. 1391: 1947, pp. 11 and 17.

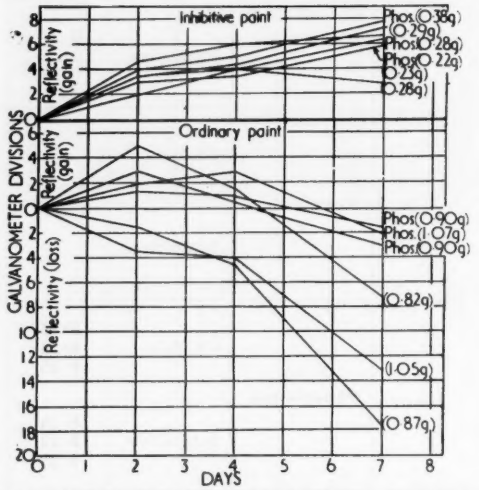

Fig. 14—Light-reflection change due to rusting

Table IV

RESULTS OF LABORATORY AND OUTDOOR EXPOSURE TESTS ON UNPAINTED STEEL

Specimen	Coating	Coating wt, g/sq.ft.	Laboratory Test, 9 Days			Outdoor Exposure		Order of Merit*
			Gain in wt on Corrosion, g/sq.ft.	Loss of Steel by Corrosion, g/sq.ft.	Order of Merit*	Gain in wt on Corrosion, g/sq.ft., 60 days	Loss of Steel by Corrosion, g/sq.ft., 112 days	
A	Iron manganese	4·04	0·19	0·44	2	0·013	0·48	1
B	Manganese	0·74	1·32	2·21	5	8·31	22·51	5
C	Iron manganese	1·26	0·92	1·14	3	7·58	20·85	4
D	Zinc	1·15	0·32	0·36	1	2·61	13·07	2
E	Iron	0·88	0·85	1·62	4	6·05	18·98	3
Bare Steel	...	...	3·17	6·59	6	10·92	27·32	6

The order of merit is derived from the losses in weight given

Pre-treatment by phosphating shows to advantage for both types of paint.

The experiment indicates that the measurement of corrosion by means of light reflection has limitations, and could only be used as a standard of measurement under conditions where the type of rusting is defined, and preferably when supplemented by weight-increment determinations.

The inhibitive paint is clearly more efficient than ordinary paint in restricting the spread of rust at damaged areas, but it is doubtful whether the assessment of the protective value of a coating by this means is entirely reliable in the case of thick coatings, where the deeper scratch may retain more corrosive solution than in the case of thin coatings. There appears to be some evidence in Fig. 15 and in the photographs (Figs. 10–12) that the spread of rust at the damaged areas on thick coatings is generally greater than on thin.

Tests on Unpainted Phosphated Steel

Although the practical value of phosphating processes in rust prevention is commonly believed to be realized only when the coatings form bases for paint or oil, they are intrinsically more resistant to corrosion than bare steel. The comparative corrosion resistances of steel specimens coated with various types of phosphate have been determined by means of the condensation-corrosion apparatus and under conditions of outdoor exposure, partly with the object of extending the scope of the test to materials of protective value intermediate between that of painted steel and bare steel, and also as a preliminary step towards finding whether there is any correlation between corrosion resistance of the coatings *per se* and their corrosion resistance when coated with paint.

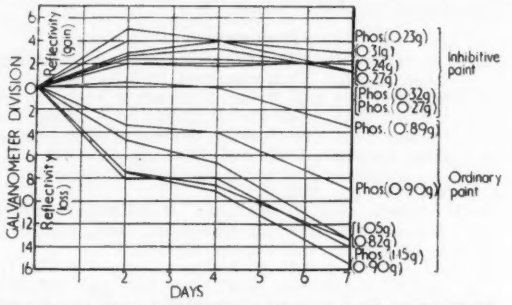

Fig. 15—Light-reflection change at artificial scratch (Low SO_2)

A number of 6-in × 4-in specimens cut from 20-gauge sheet were prepared for phosphating by shot-blasting and degreasing in trichlorethylene vapour. Coatings of zinc, manganese, and iron phosphate were formed on the specimens, half of the number being exposed in the beaker apparatus and a duplicate set exposed outdoors.

The degree of severity of the corrosion conditions in the beaker was reduced compared with those for painted specimens ; a concentration of 0·0014 g per 100 ml of sulphur dioxide was used, the temperature of the solution being raised to 50° C only, at which point the steam was shut off and the apparatus allowed to cool. The operation was repeated daily for nine days, the specimens being removed periodically and weighed after drying at 100° C. During part of the time, porcelain boats were suspended under the lower edge of the specimens in order to ascertain whether any appreciable amount of condensate ran off the panels, carrying with it phosphate coating in solution. The amount of solution in the boats, however, was negligible and a further experiment was carried out using similar specimens ; a sulphur-dioxide solution of five times the previous strength was added every two hours throughout the day and, as before, the temperature was raised to 50° C at each addition. The solution in the beaker was examined after one day, for zinc, manganese, iron, and phosphate. Traces of phosphate were found, and iron was detected in all the solutions, but manganese and zinc were not.

Periodical weighings of the outdoor specimens were made and, at the end of the tests, all the panels were stripped of both phosphate coating and corrosion products by solution in warm dilute sulphuric acid containing an inhibitor. By deducting the amount of phosphate coating, as determined on another set of specimens, from the total loss in acid, the loss of steel due to corrosion was obtained. Particulars of the coatings and test results are given in Table IV.

The figures for gain in weight on corrosion outdoors are given for 60 days' exposure, as after that period losses of corrosion product became significant, and weight changes were of no value for test purposes.

The correlation between the results for laboratory and outdoor tests is satisfactory, a Spearman Ranking Coefficient* of 0.8 being obtained from the orders of merit based on losses on de-rusting, and a coefficient of 1·0 on the order based on weight gains. As the coating-weight determinations were made on separate specimens, phosphated at the same time as the test specimens, it is possible that in certain cases the small differences in coating weights could alter the order of merit as determined by gains and losses. This may explain the different orders of merit which were found in the laboratory test.

There is also a correlation between corrosion resistance (outdoors) and coating weight. The ranking coefficient in this case is 0·7, which must be regarded as probably significant, considering that other factors besides thickness of phosphate coatings may influence corrosion and are not taken into account in the calculation. In this connection, the high value for the corrosion resistance of specimen *A*, which had a very much thicker coating than any other, is of interest. Of the five, this specimen alone was found to be a non-conductor of electricity when tested in the dry state with a Megger tester. It is possible that a coating of the thickness of that of *A* has completely covered all the high spots produced in the process of shot-blasting the basis steel. The roughness index of a grit-blasted steel surface is about 0·1 mil,[2] and that of a shot-blasted surface is probably of the same order. The value of 0·1 mil represents the root mean square of the distance of irregularities from a datum line, and some of the peaks in the surface would be higher than that. The thickness of a phosphate-coating weight of 0·3 g/sq.ft. is approximately 0·05 mil.[2] On the assumption of a coating density of approximately 3·0, the thicknesses of the coatings on specimens *A*, *B*, *C*, *D*, and *E* in Table IV may be calculated to be 0·7, 0·1, 0·2, 0·2, and 0·15 mil respectively, and these are roughly proportional to those given in the First Report of the Methods of Testing (Corrosion) Sub-Committee.[2] Only the coating on specimen *A*, however, has completely covered the peaks in the basis steel, as shown by its insulating property. Other work shows that much thinner coatings on smooth steel, when uniform, are also non-conductors, so that the electrical resistance may form the basis of a method of measuring the efficiency with which a metal surface has been phosphated.

It may be concluded from the results given that an efficient phosphate coating of the order of thickness similar to that of a thin paint film has a corrosion resistance considerably greater than that of unprotected steel.

GENERAL OBSERVATIONS AND CONCLUSIONS

The results of the experimental work show that a simple condensation-corrosion test affords a means of evaluating, within a reasonable time, the comparative corrosion resistances of the commoner types of protective coatings and pre-treatments of steel before painting. There is a sufficiently wide margin between the corrosion of phosphated and untreated painted steel, as measured by weight increases, to furnish a quantitative basis of comparison for them. It has only been possible to correlate the results of laboratory tests with those from outdoor exposure in the case of unpainted phosphated specimens, and the correlation for painted specimens remains to be determined. The correlation of laboratory with outdoor exposure tests must vary with the type of atmosphere, and probably also with the type of weather experienced at the time of the test, and it is unlikely that any one form of laboratory test will give perfect correlation for all types of atmosphere. Where the effect of light is to be included, a laboratory test enters the more comprehensive field of weathering of protective coatings, but most simple short-time corrosion tests aim only at determining the relative corrosion-resistance value of coatings and are not directed to determining their probable life. The condensation-type corrosion test and other simple corrosion tests are of this type, and reproducibility of results is of particular importance, implying efficient control of all factors open to variation. The beaker test fulfils these conditions at reasonable cost.

Although more confidence must be placed in weight changes as the criterion of corrosion, the measurement of light reflection may have a restricted usefulness in this respect, either alone or in conjunction with weight increments. The incidence of bleaching might be offset by the application of a correction factor.

One result of testing unpainted phosphated coatings may have interesting possibilities, *viz.*, the application of coatings of phosphate sufficiently thick and dense to prevent access of the atmosphere to the basis steel. Such coatings assume some of the functions of a paint coating without many of its disadvantages.

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* Calculated from the formula $-6(d_1^2 + d_2^2 \ldots + d_n^2)/n(n^2-1)$, in which d represents the arithmetical difference between the ranking orders under comparison, and n the number of samples in each set.

The Influence of Teeming Times on Ingot Surface Defects

By W. E. Goodrich, M.Met., F.I.M., A.M.I.Mech.E.

SYNOPSIS

Details are recorded of data accumulated during long-period observations made at various stages of rolling and forging operations on steel ingots, and illustrations are given indicating the application of the information to establish ideal ingot teeming times. Variations in steel composition and quality, mould design and dimensions, and ladle-nozzle sizes are considered. Optimum teeming times are deduced for a variety of steels and mould sizes.

Introduction

PREVIOUS investigations have shown that during hot working there is an optimum teeming time when the presence of surface defects in an ingot is at a minimum. By teeming at a faster rate than the optimum teeming time, a weak crystal structure is developed in the ingot, thereby yielding a greater tendency to the formation of transverse and longitudinal breaks. A slower rate of teeming will cause skulling, with possible entrapment in the form of teeming laps.

The difference between the two types of defect is fairly easily observed, as each has its own characteristics. Thus, by teeming too quickly the outer skin of the ingot is weak, and the ferrostatic pressure, due to delayed solidification within the skin, tends to rupture it. Usually this type of defect is located in the bottom half of the ingot. On rolling or forging, the discontinuities may not be apparent immediately, and, especially in the case of forging, the skin may not rupture until an appreciable amount of hot deformation has been carried out.

Teeming too slowly causes a skin of partially solidified and somewhat oxidized metal to form round the periphery of the liquid surface. As the metal rises this skull floats up, thickens, and spreads, until, becoming too heavy or locally attached to the mould face, the still-molten metal flows over it, forming what are commonly known as teeming laps or overlaps. Unless the metal is in exceptionally bad condition or the nozzle much too small, this type of defect will occur principally in the top half of the ingot. Such laps are easily recognized as they can usually be detected on stripping the ingot and invariably open up on the first pass or squeeze ; they are referred to as skull breaks or teeming laps.

It was the purpose of this investigation to determine the critical speed of teeming at which defects will be at a minimum. Tests were made to find the optimum teeming times for some of the more common types of ingots in use, and also to investigate the degree in which the more important variables affect these times. The whole investigation was based on a detailed study of several thousand casting and forging records.

PROCEDURE

The following method was adopted to determine the optimum teeming times. Firstly, each ingot observed was classified according to its surface condition on rolling or forging and placed in one of the following grades :

Grade 1. No defects, or defects negligible in their effects

Grade 2. Defects present, but moderate in number and size

Grade 3. Defects of a serious nature.

N.B.—The defects considered were those which were definitely related to the teeming speed, chiefly transverse breaks and skull breaks.

The forged-ingot grade number was then correlated with the body teeming time for a large number of each type of ingot under consideration, and from these lists the percentage frequency of each grade occurring at the various teeming times was calculated. Then, for each type of ingot of similar chemical composition, a set of curves was obtained by plotting the percentage frequencies of each grade occurring against the respective body teeming times. These, if extrapolated to the extremes of teeming time, would yield a diagram such as that shown in the top graph of Fig. 1.

A total of 35 teeming charts* of this type was compiled from the data obtained on 4089 ingots, all of which were top poured direct from the ladle. Several typical graphs are shown in Fig. 2, and Table III records the effect of variations from the optimum teeming time on the frequency of grade 1 ingots.

The chemical compositions of the steels, and dimensional details and weights of the ingots, are recorded in Tables I and II.

The optimum teeming times, being the times which yielded the greatest number of grade 1 ingots, are recorded in Table III.

Paper SM/BD/142/47 of the Ingot Surface Defects Sub-Committee of the Steelmaking Division of the British Iron and Steel Research Association, received 24th June, 1948. The views expressed are the author's and are not necessarily endorsed by the Committee as a whole.

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* A complete set of charts has been lodged with the library of The Iron and Steel Institute.

Table I
CHEMICAL COMPOSITION OF STEELS

Steel	C	Mn	Si	S	P	Ni	Cr	Mo	V
A	0·20/0·45	0·60/0·80	0·20/0·25	0·035 max.	0·035 max.	...	...	...	...
B	0·30/0·34	1·0/1·2	0·20/0·25	0·030 ,,	0·030 ,,	0·7/0·9	0·5 max.	0·25/0·35	...
C	0·28/0·32	0·40/0·60	0·20/0·25	0·030 ,,	0·030 ,,	2·8/3·0	0·5/0·8	0·2/0·5	0·07
D	0·32/0·36	0·50/0·70	0·20/0·25	0·030 ,,	0·030 ,,	2·8/3·0	0·7/0·9	0·45/0·55	0·06/0·08
E	0·32/0·34	0·40/0·60	0·20/0·25	0·020 ,,	0·020 ,,	3·1/3·4	0·6/0·8	0·4/0·6	0·06/0·08
F	0·26/0·30	0·60/0·80	0·20/0·25	0·030 ,,	0·030 ,,	0·70/0·90	1·6/1·7	0·35/0·40	0·06/0·08
G	0·26/0·30	0·40/0·50	0·20/0·25	0·030 ,,	0·030 ,,	3·6/3·8	1·6/1·8	0·40/0·45	0·06/0·08

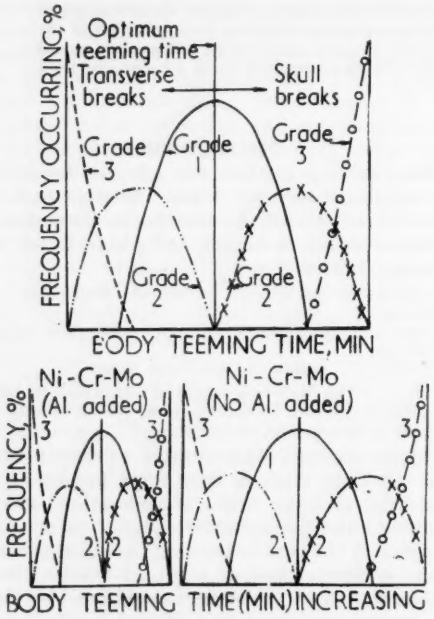


Fig. 1—Quality of ingot surfaces versus teeming times. (Theoretical curves)

POINTS DERIVED FROM GRAPHS

Steel Composition

The effect of steel composition is explained by the data below. In addition to its effect on the optimum teeming times the composition was also found to influence the maximum percentage of grade 1 ingots obtained.

Rectangular Ingots	Optimum Teeming Time, min, Steel *G* (Al treated)	Optimum Teeming Time, min, Steel *F* (Al treated)	Percentage Grade 1 at O.T.T., Steel *G* (Al treated)	Percentage Grade 1 at O.T.T., Steel *F* (Al treated)
115 cwt	5½	4	77	88
10½ tons	5½	4½	74	85
14 tons	6½	4¾	64	78
20 tons	6¾	5¾	64	76

Octagonal Ingots	Steel *C* (no Al)	Steel *A* or *B* (no Al)	Steel *C* (no Al)	Steel *A* or *B* (no Al)	
N	18½	17	85	100	Teeming range 4 min
A	17½	16	90	100	

It can be seen from these data that certain classes of steel, particularly those containing nickel and chromium, are more susceptible to defects than others, and for these it is particularly necessary to establish careful control of teeming speeds.

Charge Quality

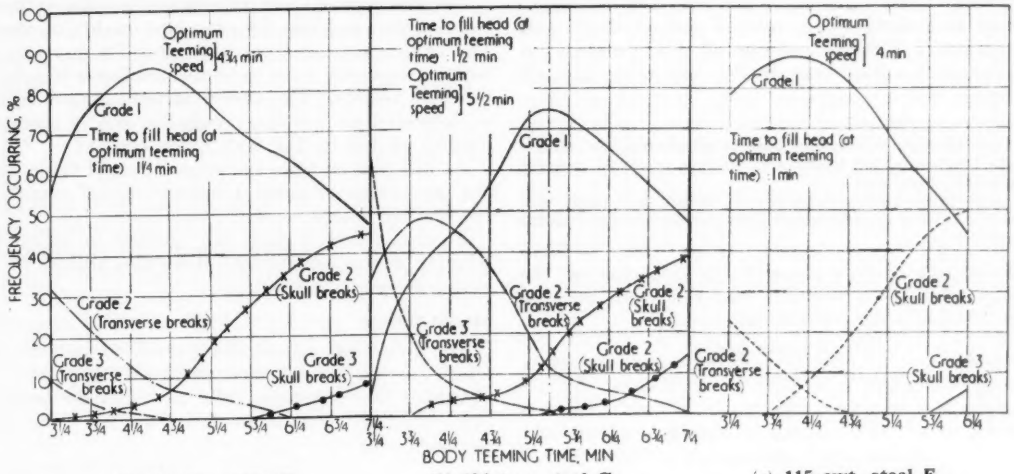
A routine method of assessing the quality of the finished steel is to make an inspection of slag and metal samples drawn during refining, and a study of

Table II
INGOT BODY DIMENSIONS AND WEIGHTS
Rectangular Ingots

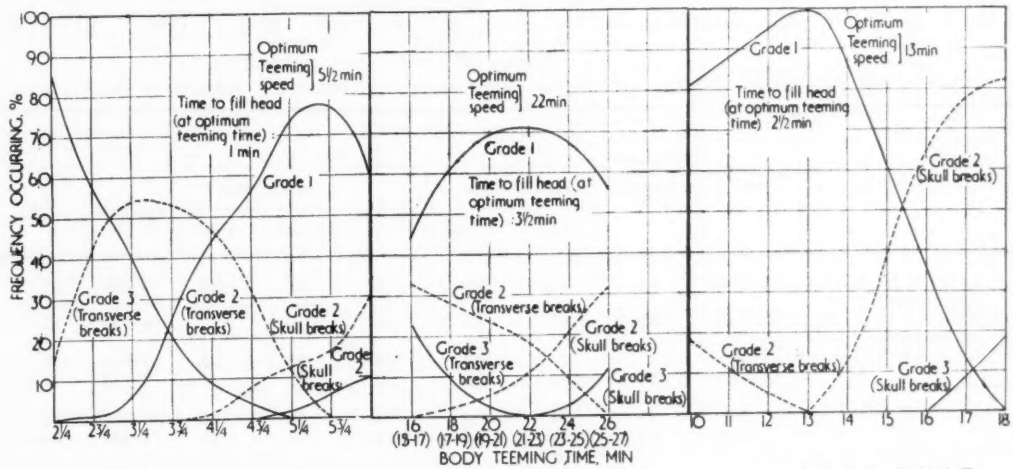
Ingot Wt, tons	Number Examined	Bottom, in	Top, in	Length, in	Body Wt, tons	Total Wt, tons
55 cwt	161	17 × 22	18½ × 23½	44	2	2·75
115 cwt	374	20 × 28	23 × 30	64	4	5·75
10½	906	26 × 35	30 × 36	70	8	10·35
14	726	33·5 × 40·5	41 × 41	66	10	13·14
20	140	38 × 44·5	44 × 45	78	19	22·5

Octagonal Ingots

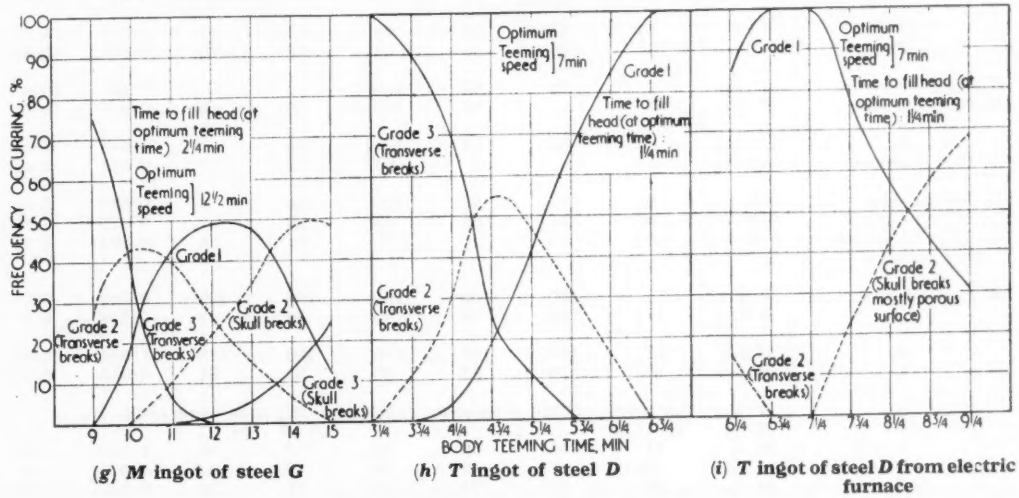
Ingot	Number Examined	Bottom Across Flats, in	Top Across Flats, in	Length, in	Body Wt, tons	Total Wt, tons
T	306	20	22	70	3·21	3·86
S/X	172	24	26	70	4·49	5·81
S/W	332	27	29	78	6·21	8·0
A	182	33	35	105	12·33	15·60
N	273	36·5	38·5	110	15·86	19·96
M	507	40	42	120	20·70	24·86


FREQUENCY OCCURRING, %
Optimum Teeming speed 4¾ min
Grade 1
Time to fill head (at optimum teeming time) 1¼ min
Grade 2 (Transverse breaks)
Grade 2 (Skull breaks)
Grade 3 (Transverse breaks)
Grade 3 (Skull breaks)
Time to fill head (at optimum teeming time) 1½ min
Optimum Teeming speed 5½ min
Grade 1
Grade 2 Transverse breaks
Grade 2 (Skull breaks)
Grade 3 (Transverse breaks)
Grade 2 (Skull breaks)
Optimum Teeming speed 4 min
Grade 1
Time to fill head (at optimum teeming time) 1 min
Grade 2 (Skull breaks)
Grade 2 (Transverse breaks)
Grade 3 (Skull breaks)
BODY TEEMING TIME, MIN

(*a*) **10½-ton, steel *F*** (*b*) **10½-ton, steel *G*** (*c*) **115-cwt, steel *F***


FREQUENCY OCCURRING, %
Optimum Teeming speed 5½ min
Time to fill head (at optimum teeming time) 1 min
Grade 1
Grade 3 (Transverse breaks)
Grade 2 (Transverse breaks)
Grade 2 (Skull breaks)
Optimum Teeming speed 22 min
Grade 1
Time to fill head (at optimum teeming time) 3½ min
Grade 2 (Transverse breaks)
Grade 2 (Skull breaks)
Grade 3 (Transverse breaks)
Grade 3 (Skull breaks)
Optimum Teeming speed 13 min
Grade 1
Time to fill head (at optimum teeming time) 2½ min
Grade 2 (Skull breaks)
Grade 2 (Transverse breaks)
Grade 3 (Skull breaks)
(19-17) (17-19) (19-21) (21-23) (23-25) (25-27)
BODY TEEMING TIME, MIN

(*d*) **115-cwt, steel *G*** (*e*) ***M* ingot of steel *C*** (*f*) ***M* ingot of steel *F***


FREQUENCY OCCURRING, %
Time to fill head (at optimum teeming time) 2¼ min
Optimum Teeming speed 12½ min
Grade 1
Grade 2 (Transverse breaks)
Grade 3 (Transverse breaks)
Grade 2 (Skull breaks)
Grade 3 (Skull breaks)
Optimum Teeming speed 7 min
Grade 3 (Transverse breaks)
Grade 1
Time to fill head (at optimum teeming time) 1¼ min
Grade 2 (Transverse breaks)
Optimum Teeming speed 7 min
Grade 1
Time to fill head (at optimum teeming time) 1¼ min
Grade 2 (Skull breaks mostly porous surface)
Grade 2 (Transverse breaks)
BODY TEEMING TIME, MIN

(*g*) ***M* ingot of steel *G*** (*h*) ***T* ingot of steel *D*** (*i*) ***T* ingot of steel *D* from electric furnace**

Fig. 2—Typical teeming charts for steel ingots

the charge history, including mixture, melt-out time, carbon at melted stage, rate of carbon drop, and temperature. For the purpose of this investigation the charge qualities were divided into three distinct groups :

(i) Good charges
(ii) Charges which had been worked cold, but which had been carefully controlled to give reasonably good finishing conditions
(iii) Poor quality charges in which the bath was over-oxidized during refining, resulting in a fluid metal lacking body.

Estimated in this manner the influence of the charge quality on teeming conditions can be seen from the following comparisons :

Ingot Wt, tons	Steel	Optimum Teeming Time, min: Good Charges	Cold-Worked Charges	Over-oxidized Charges
10½	*F*	5¼	4½	4¾
10½	*G*	5¾	5	5½
14	*G*	6¼	5½	6
		Percentage Grade 1 at O.T.T.		
10½	*F*	90	87	70
10½	*G*	86	83	58
14	*G*	78	60	51

The first part of these data shows that the optimum teeming time is greatest for the best quality of charge. The cold-worked charges are naturally more sticky and consequently have to be teemed faster to achieve the best results. The over-oxidized charges occupy an intermediate position, probably due to increased fluidity caused by the high oxide content.

As will be seen from the second part of these data, the percentage of grade 1 ingots falls off rapidly as the quality deteriorates.

Figures 3 and 4 show the manner in which the teeming charts are influenced by the quality of the steel assessed in this way.

Mould Design

The following comparison serves to indicate the effect of the mould cross-sectional shape on the optimum teeming time, the two moulds being of approximately the same body weight and cross-sectional area :

Ingot		Body Wt, tons	Cross-Section, sq.in.	Optimum Teeming Time, min: Steel *G*	Steel *F*
20-ton	Rectangular	19	1825	6¾	5¾
M	Octagonal	20·7	1480	12½	13

Table III

OPTIMUM TEEMING TIMES YIELDING GREATEST NUMBER OF GRADE 1 INGOTS

Steel	Mould Wt, tons	Optimum Teeming Time, min	Percentage Grade 1 at, and close to, Optimum Teeming Time: O.T.T. Minus 1 min	O.T.T. Minus ½ min	At O.T.T.	O.T.T. Plus ½ min	O.T.T. Plus 1 min	Average Rate of Flow at O.T.T.: Tons/min	Rise, in/min
F, 1¼% Cr–Ni–Mo (Al treated)	55 cwt	2¼	...	88	89	87	83	0·889	19·55
G, 3½% Ni, 1½ Cr–Mo (Al treated)	55 cwt	3¾	67	83	90	...	...	0·533	11·73
F	115 cwt	4	...	83	88	85	75	1·00	16·0
G	115 cwt	5½	50	65	77	72	...	0·727	11·63
F	10½	4¾	74	83	84	76	68	1·68	14·74
G	10½	5½	50	65	74	68	70	1·451	12·73
F	14	4¾	59	74	78	76	69	2·113	13·9
G	14	6¼	51	60	64	57	41	1·605	10·56
F	20	5¾	52	68	76	72	57	3·315	13·56
G	20	6¾	45	56	64	45	30	2·806	11·55
D, 3% Ni–Cr–Mo	*T* (3½)	7	76	93	100	...	...	0·46	10·0
D, Elec. furnace	*T* (3½)	7	...	95	100	93	66	0·46	10·0
D	*S/X* (4½)	8¼	86	95	100	86	...	0·543	8·48
D, Elec. furnace	*S/X* (4½)	8¼	...	...	95	84	77	0·543	8·48
B, Mn–Ni–Mo	*S/W* (6½)	9	82	98	100	100	...	0·689	8·66
C, 3% Ni–Cr–Mo	*S/W* (6½)	10	71	81	85	80	...	0·621	7·8
E, 3¼% Ni–Cr–Mo elec. furnace	*S/W* (6½)	10½	...	...	77	66	50	0·592	7·43
A, Carbon steel	*A* (12½)	16	100	100	100	100	100	0·768	6·56
C	*A* (12½)	17½	88	89	90	90	87	0·748	6·4
A	*M* (16)	17	100	100	100	100	100	1·034	6·49
C	*M* (16)	18½	79	83	85	81	81	0·856	5·95
A	*M* (20½)	All ingots within a teeming range of 7–28½ min were grade 1							
B	*M* ,,	,, ,,	,,	,,	,,	,, 15–28 min	,,	,,	
F	*M* ,,	13	95	98	99	97	86	1·587	9·23
G	*M* ,,	12½	47	49	50	48	42	1·651	9·6
C	*M* ,,	22	71	71	71	71	70	0·937	5·45

The trend of the influence of the tapered faces of rectangular moulds is shown by the following :

Ingot Wt, tons	Percentage Grade 1 at Optimum Teeming Time: Steel *G*	Steel *F*	Mould Factors: Length/Width	Face Taper, in/ft	Side Taper, in/ft
115 cwt	77	88	2·54	0·565	0·375
10½	74	85	2·24	0·684	0·171
14	64	78	1·67	1·454	0·092
20	64	76	1·82	0·932	0·077

Although the interpretation of these results is complicated by the difference in length/width ratio, it is probable that the definite drop, apparent in both qualities of steel, is largely due to the very small taper on the side panels of the 14-ton and 20-ton sizes.

Another feature is that the range of occurrence of grade 1 ingots appears to be affected by the actual mould size in addition to the foregoing factors ; that is, the larger the ingot, the greater the latitude in optimum teeming time, and this is particularly noticeable in the case of octagonal ingots.

Aluminium Additions

Identical steels with and without aluminium addition were, unfortunately, not available, but an indication of its effect on the optimum teeming time can be seen from the comparison between three steels, *G*, *F*, and *C*, of ingot *M*. The optimum teeming times for steels *G* and *F*, with aluminium addition, were 12½ and 13 min. respectively. For steel *C*, with no aluminium addition, the optimum teeming time was considerably slower, *viz.*, 22 min.

Its effect on the percentage-frequency graphs is to narrow the permissible teeming range, particularly for grade 1 ingots. This is shown by the two graphs on the lower portion of Fig. 1.

NOTE ON DATA ON ELECTRIC-FURNACE STEELS

By reason of the reduced ferrostatic pressure in the ladle, the teeming of the electric-furnace steel was somewhat slower in practice than that of the acid open-hearth steel for any particular size of nozzle. Because of this, the information collected on steels from the electric furnace tended to give results on the slow teeming side of the diagrams. In the case of such ingots the optimum teeming time was found to coincide with that of similar ingots cast from the acid open-hearth furnace. It was also very noticeable that the shape of the curves, in the part of the diagrams representing electric-furnace ingots, *viz.*, the slow teeming side, coincided very well with the shape of those for the same positions in the diagrams representing similar acid open-hearth ingots. A point worthy of notice in connection with electric-furnace steels was that, from the position of the data on the diagrams, the porous or spongy surface often occurring on such ingots is related to the initial stages of skull breaks or teeming laps.

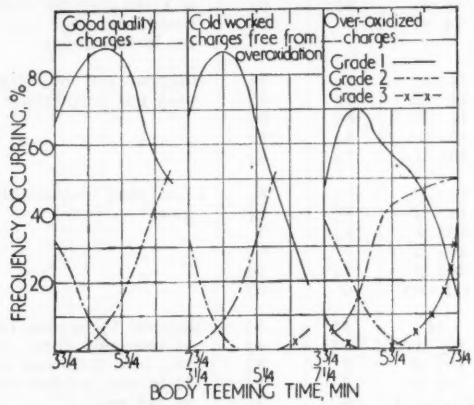


Fig. 3—Influence of quality on teeming time, for 10½-ton ingots of steel *F*

EFFECT OF STEEL TEMPERATURE

Unfortunately routine temperature measurement in the melting shop and pit side was not in regular operation at the time this investigation was carried out. An approximation of metal temperatures was assessed, however, from observations of bath condition and slag and metal samples, and was considered when classifying the quality of the charge.

Although it was recognized that any marked variation in teeming temperature would have an influence on the optimum teeming time, it was considered that insufficient evidence was available, in this investigation, to justify an assessment of its influence.

In view of the large number of casts reviewed, most of which were worked under standard conditions, it seemed feasible to assume that the possible inclusion of a few casts teemed at extremes of temperatures would not materially affect the validity of the other evidence.

RATE OF METAL FLOW FROM THE LADLE NOZZLES

With the optimum teeming times established for the various sizes of ingots it was then desirable to find the most suitable sizes of nozzles to use, in order that the moulds be filled in the desired time. Curves were therefore compiled to indicate the weight of metal passed through any particular nozzle, over the complete range of time during the discharge of the ladle contents ; these curves really took the form of bands, due to varying metal conditions. Table IV lists the curves determined and illustrations of them are given for both electric-furnace and acid open-hearth steels in Figs. 5 and 6.

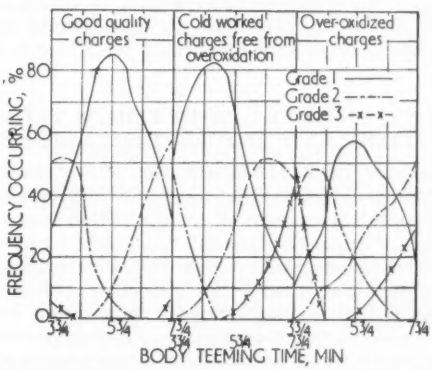


Fig. 4—Influence of quality on teeming time, for 10½-ton ingots of steel *G*

Table IV

RATE-OF-FLOW CURVES DETERMINED

Nozzle Size, in	Steel	Wt of Charge, tons	Ingots Considered
$\frac{7}{8}$ Magnesite-plug	*C*	40/50	*M, N, A, S/W, L/X, S/X, T,*
,,	*C*	65	*M, N, A*
,,	*A* and *B*	40/50	*M, N, A, L/E*
,,	*A* and *B*	65	,,
$1\frac{1}{4}$ Magnesite-plug	*F*	40/50	
,,	*F*	65	
,,	*G*	40/50	17-ton, 14-ton, $10\frac{1}{2}$-ton, 115-cwt and 55-cwt
,,	*G*	65	
$1\frac{1}{2}$ Magnesite-plug	*F*	40/50	
,,	*F*	65	
,,	*G*	65	
$1\frac{1}{4}$ Clay-pot	*G*	40/50	
$1\frac{1}{2}$,,	*F*	40/50	
*$\frac{3}{4}$ Magnesite-plug	*D* and *E*	16/18	*L/E, S/W, S/X, T*
*$\frac{7}{8}$,,	*D* and *E*	16/18	,,
*1 ,,	*D* and *E*	16/18	,,

* Electric-furnace steels

For octagonal ingots of acid open-hearth steel, types *C*, *D*, *E*, of sizes up to that of *S/X*, it was considered that the $\frac{3}{4}$-in magnesite-plug nozzle was the most suitable for normal casts. From the foregoing rate-of-flow curves it was apparent that for octagonal ingots of the same types of steel, larger than the *S/X* size and up to the *M* size, the $\frac{7}{8}$-in magnesite-plug nozzle was desirable. This latter size of nozzle was applicable to the casting of octagonal ingots of carbon steel throughout the whole range up to the *M* ingots.

With rectangular ingots of the steels *F* and *G* (aluminium treated), where there is not so much latitude in the range of optimum teeming times for maximum quantity of grade 1 ingots, several sizes and types of nozzles had to be considered. The data given in Tables V and VI were derived from the rate-of-flow curves when using various nozzles, and the recommendations for different ingot sequences were assessed from these data.

In the case of electric-furnace steels, careful control of nozzle size was required because of the reduced ferrostatic pressure in the ladle and the increased ratio of ingot size to total weight of liquid metal. A similar teeming analysis to that carried out on acid open-hearth alloy-steel charges is given in Table VII.

RELATION BETWEEN OPTIMUM TEEMING TIME AND MOULD DIMENSIONS

Since, by the methods described, the determination of teeming diagrams is dependent on the accumulation of a considerable amount of information over a long period of time, an attempt was made to ascertain some relationship between the optimum teeming time for a particular composition of steel and mould shape, in order that it might rapidly be assessed for any other size of ingot. From the teeming diagrams already produced it was noticeable that a relationship existed between : (*a*) the average cross-sectional area of the mould, and the weight of metal poured per minute at the optimum teeming time, and (*b*) the average rate of rise in the mould at the optimum teeming time, and the " chill " length of the ingot. Typical graphs of these relationships for octagonal ingots of

Table V

STEEL G

IDEAL TEEMING TIME FOR WHOLE INGOT, MIN

14-ton—$7\frac{3}{4}$
$10\frac{1}{2}$-ton—7
115-cwt—$6\frac{1}{4}$

Sequence of Ingot Wt, tons	Total Teeming Time, min		Recommendations
	$1\frac{1}{4}$-in Clay Pot	$1\frac{1}{4}$-in Magnesite Plug	
	40–50-ton Charges		
14 (1)	8	$7\frac{3}{4}$	$1\frac{1}{4}$-in clay pot most suitable
14 (2)	$8\frac{1}{4}$	$9\frac{3}{4}$	
14 (3)	$7\frac{3}{4}$	11	
14 (1)	8	$7\frac{3}{4}$	$1\frac{1}{4}$-in clay pot most suitable
14 (2)	$8\frac{1}{4}$	$9\frac{3}{4}$	
$10\frac{1}{2}$	$6\frac{1}{2}$	$8\frac{1}{2}$	
14	8	$7\frac{3}{4}$	Suggest $1\frac{1}{4}$-in plug for 14-ton and first $10\frac{1}{2}$-ton, and $1\frac{1}{4}$-in plug for remaining $10\frac{1}{2}$-ton
$10\frac{1}{2}$ (1)	$6\frac{1}{2}$	$7\frac{1}{2}$	
$10\frac{1}{2}$ (2)	6	$8\frac{1}{2}$	
$10\frac{1}{2}$ (1)	$6\frac{1}{2}$	$6\frac{1}{4}$	Difficult sequence to handle. Suggest $1\frac{1}{4}$-in plug for first two, and $1\frac{1}{4}$-in clay pot for remaining two
$10\frac{1}{2}$ (2)	$6\frac{1}{2}$	$7\frac{1}{4}$	
$10\frac{1}{2}$ (3)	$6\frac{3}{4}$	$8\frac{1}{4}$	
$10\frac{1}{2}$ (4)	$6\frac{1}{2}$	$9\frac{1}{4}$	
14	8	$7\frac{3}{4}$	$1\frac{1}{4}$-in plug suitable for 14-ton and $10\frac{1}{2}$-ton. Suggest $1\frac{1}{4}$-in plug for two at 115 cwt
$10\frac{1}{2}$	$6\frac{1}{2}$	$7\frac{1}{2}$	
115 cwt (1)	4	$4\frac{3}{4}$	
115 cwt (2)	$3\frac{1}{4}$	5	
$10\frac{1}{2}$ (1)	$6\frac{1}{4}$	$6\frac{1}{4}$	Suggest $1\frac{1}{4}$-in plug for two at $10\frac{1}{2}$-ton, and $1\frac{1}{4}$-in clay pot for three at 115 cwt
$10\frac{1}{2}$ (2)	$6\frac{3}{4}$	$7\frac{1}{4}$	
115 cwt (1)	$3\frac{3}{4}$	$4\frac{1}{4}$	
115 cwt (2)	$3\frac{1}{2}$	5	
115 cwt (3)	$3\frac{3}{4}$	$5\frac{1}{4}$	
	65-ton Charges		
14 (1)	$7\frac{1}{4}$	$5\frac{1}{2}$	Sequence difficult to handle. Suggest use of $1\frac{1}{4}$-in clay pot with possible change to $1\frac{1}{2}$-in. in last ingot
14 (2)	$8\frac{1}{4}$	$5\frac{3}{4}$	
14 (3)	$8\frac{3}{4}$	$6\frac{1}{2}$	
14 (4)	9	$7\frac{1}{2}$	
14 (1)	$7\frac{1}{4}$	$5\frac{1}{2}$	Suggest use of $1\frac{1}{4}$-in clay pot throughout
14 (2)	$8\frac{1}{4}$	$5\frac{3}{4}$	
14 (3)	$8\frac{3}{4}$	$6\frac{1}{2}$	
$10\frac{1}{2}$ (1)	$6\frac{3}{4}$	$5\frac{3}{4}$	
$10\frac{1}{2}$ (2)	$7\frac{3}{4}$	$6\frac{1}{4}$	
14 (1)	$7\frac{1}{4}$	$5\frac{1}{2}$	$1\frac{1}{4}$-in plug reasonably good
14 (2)	$8\frac{1}{4}$	$5\frac{3}{4}$	
$10\frac{1}{2}$ (1)	$6\frac{3}{4}$	5	
$10\frac{1}{2}$ (2)	7	$6\frac{3}{4}$	
$10\frac{1}{2}$ (3)	$7\frac{1}{4}$	$6\frac{1}{4}$	
115 cwt	6	$5\frac{1}{4}$	
14	$7\frac{1}{4}$	$5\frac{3}{4}$	Suggest $1\frac{1}{4}$-in plug for 14-ton and three at $10\frac{1}{2}$ ton, followed by $1\frac{1}{4}$-in clay pot for two at 115 cwt
$10\frac{1}{2}$ (1)	$6\frac{1}{2}$	$4\frac{3}{4}$	
$10\frac{1}{2}$ (2)	7	$5\frac{1}{4}$	
$10\frac{1}{2}$ (3)	7	$5\frac{1}{4}$	
115 cwt (1)	4	$3\frac{1}{2}$	
115 cwt (2)	$4\frac{1}{2}$	$3\frac{1}{2}$	

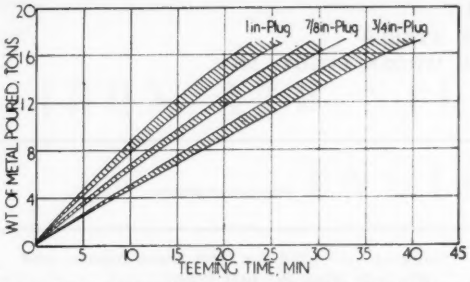


Fig. 5—Rate of flow for electric-furnace steels *D* and *E*, using various nozzles

nickel–chromium–molybdenum steels are given in Figs. 7 and 8.

The following example serves to show how this information can be applied in practice. Assuming that an octagonal ingot of nickel–chromium–molybdenum steel is to be cast into a mould with an average

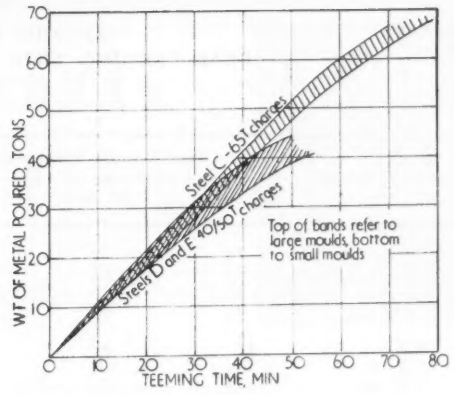

Steel C–65T charges
Steel D and E 40/50T charges
Top of bands refer to large moulds, bottom to small moulds
WT OF METAL POURED, TONS
TEEMING TIME, MIN

Fig. 6—Rate of flow for O.H. steel, using $\frac{7}{8}$-in magnesite plug

Table VI

STEEL *F*

IDEAL TEEMING TIME FOR WHOLE INGOT, MIN

14-ton—6½
10½-ton—6
115-cwt—5

Sequence of Ingot Wt, tons	Total Teeming Time, min			Recommendation
	1½-in Clay Pot	1½-in Magnesite Plug	1¼-in Magnesite Plug	
		40–50-ton Charges		
14 (1)	6½	6¼	8¼	1½-in clay pot most suitable
14 (2)	6⅝	7¼	10½	
10½	6½	6½	9	
14	6½	6¼	8¼	1¼-in magnesite plug most suitable
10½ (1)	5¼	5⅜	8	
10½ (2)	6¼	6½	9¼	
10½ (1)	5	5	6½	Suggest 1¼-in clay pot for first two ingots, and 1½-in clay pot for last two
10½ (2)	5¼	5½	7⅜	
10½ (3)	5⅜	6⅛	8⅜	
10½ (4)	6⅜	7¼	10¼	
		65-ton Charges		
14 (1)	...	5¼	7¼	Suggest 1½-in magnesite plug throughout
14 (2)	...	6¼	8¼	
14 (3)	...	6⅜	9⅜	
14 (4)	...	8¼	11½	
14 (1)	...	5½	7¼	Suggest 1½-in magnesite plug for first two 14-ton and 1½-in clay pot for remainder
14 (2)	...	6¼	8½	
14 (3)	...	6⅜	9⅜	
10½ (1)	...	6½	9	
10½ (2)	...	8½	10½	
14 (1)	...	5½	7¼	The 1½-in magnesite plug is quite suitable except in the case of third 10½ ton. This suggests that, if possible, the sequence be altered to two at 14 ton, two at 10½ ton and three at 115 cwt
14 (2)	...	6¼	8¼	
10½ (1)	...	6¼	7½	
10½ (2)	...	6½	8⅜	
10½ (3)	...	7⅜	9¾	
115 cwt (1)	...	5	7	
10½ (1)	...	4½	5¾	This sequence difficult to handle. A better one would be five at 10½ ton and two at 115 cwt, and the use of a 1½-in clay pot for first three at 10½ ton, and a 1½-in magnesite plug for remainder
10½ (2)	...	4⅜	6¼	
10½ (3)	...	5½	7	
10½ (4)	...	5½	8	
10½ (5)	...	6¾	9½	
10½ (6)	...	9	11	

Table VII

ELECTRIC FURNACE STEELS

IDEAL TEEMING TIME FOR THE WHOLE INGOT, MIN

T—8½
S/X—10½
S/W—12½
A—21

Sequence of Ingots	Total Teeming Time, min			Recommendations
	¾-in Plug	⅞-in Plug	1-in Plug	
T (1)	7¾	5¾	4¼	Suggest ¾-in plug for first three ingots, and the ⅞-in plug for last ingot
T (2)	8½	6½	5	
T (3)	8¾	7	5½	
T (4)	9¼	8	6	
S/X (1)	12	8¾	6¾	The ⅞-in plug is most suitable, but teeming may be rather fast for first ingot
S/X (2)	13¼	10½	8½	
S/X (3)	14½	11¼	9¼	
S/W	17	12½	9¾	The ⅞-in plug is most suitable
S/X	13	11	8	
A	34¼	26¼	21¾	The 1-in plug is most suitable

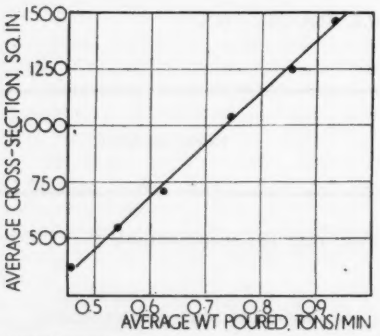


Fig. 7—Relationship between average cross-sectional area and average weight poured per min at optimum teeming time for 4–25-ton octagonal ingots of steels *C* and *D*

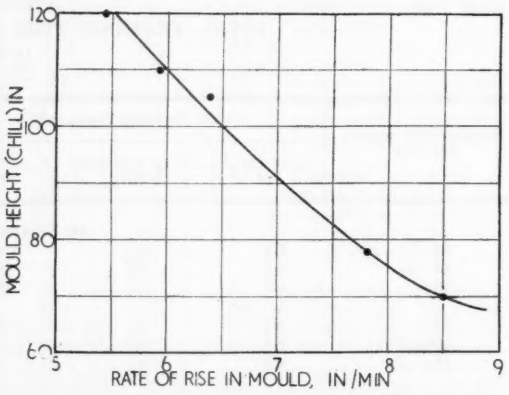


Fig. 8—Relationship between mould height and rate of rise at optimum teeming time for 4–25-ton octagonal ingots of steels *C* and *D*

cross-sectional area of 1000 sq.in., Fig. 7 shows that the average weight poured per minute, to coincide with the optimum teeming time, should be 0·74 tons. This rate of flow corresponds to a rate of rise of metal of 5·85 in/min on a cross-section of 1000 sq.in. From Fig. 8 it is apparent that the maximum suitable length of chill for this rate of rise is 113 in. If this length is used it gives the ingot a chill weight of 14·3 tons and, therefore, an optimum teeming time of 14·3/0·74, *i.e.*, 19·3 min.

Referring now to Fig. 5, it is seen that for a ⅞-in plug nozzle teeming a 40/50-ton charge, the rate of flow of 0·74 ton/min is slightly exceeded at the start of the teeming, but is just right during the teeming of the second half of the ladle content. In this example, therefore, given particulars of the type of steel, weight of charge and mould cross-section, it has proved possible to establish :

(*a*) The maximum desirable length of the mould is 113 in.

(*b*) A ⅞-in. plug nozzle is suitable for normal teeming conditions

(*c*) The ingot should be teemed from the latter part of the charge in the ladle.

CONCLUSIONS

From the foregoing review of observations on several thousand octagonal and rectangular ingots it has been possible to show definite relationships, at the optimum teeming time, between :

(1) The weight of metal teemed per minute and the average cross-sectional area of the mould

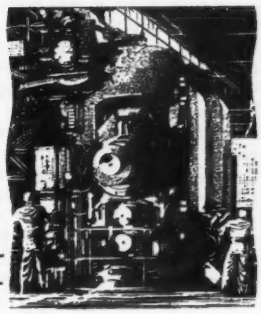
(2) The rise of metal in inches per minute and the mould height.

It is suggested that these relationships, combined with teeming charts, can be used to assess mould dimensions and teeming data for a large variety of ingots.

Acknowledgments

The author has pleasure in acknowledging the assistance of Mr. J. Sloan, B.Sc., A.I.M., and Mr. F. D. Bridge, B.Sc., A.I.M., in the observations and compilation of data from which this paper was prepared.

IRON AND STEELWORKS ENGINEERING



THE IRON AND STEEL ENGINEERS GROUP

THE IRON AND STEEL ENGINEERS GROUP

REPORT OF THE SEVENTH MEETING

THE SEVENTH MEETING OF THE IRON AND STEEL ENGINEERS GROUP of The Iron and Steel Institute was held at 4, Grosvenor Gardens, London, S.W.1, on Tuesday, 22nd June, 1948. Mr. W. F. CARTWRIGHT (Steel Company of Wales, Ltd.), Chairman of the Group, presided.

AT THE MORNING SESSION a paper on "Electric Control Gear for Steel-Mill Auxiliaries," was presented by Mr. R. A. WEST. The discussion was introduced by Mr. R. A. LAKE.

AT THE AFTERNOON SESSION Dr. J. C. READ introduced the discussion on a paper on "Electronic and Servo Electronic Controls and their application to the Iron and Steel Industry," which had been presented at the Morning Session by Dr. W. G. THOMPSON. The Session continued with a discussion, introduced by Mr. R. DINGWALL, on the paper, "The Maintenance of Electrical Machinery in Iron and Steel Works," presented by Mr. G. S. MARTIN.

PROCEEDINGS OF THE MORNING SESSION: 10.30 A.M. TO 1.0 P.M.

Discussion on ELECTRIC CONTROL GEAR FOR STEEL-MILL AUXILIARIES*

The **Chairman** (Mr. W. F. Cartwright): The whole of today's discussions will be devoted to electrical subjects. I think this is the first time in the history of The Iron and Steel Institute when that has been done. For some years now we have realized the importance of electricity and electrical engineering to the iron and steel industry, but I think it is only recently that the electrical engineers have really begun to mix with the operating engineers.

Today's paper will contribute substantially to a general understanding of the principal applications of modern electrical thought to the iron and steel industry and thus prevent the wrong type of installations.

Mr. **R. A. West** (Igranic Electric Co., Ltd., Glasgow), in presenting his paper said: In view of the discussion at the first meeting of the Iron and Steel Engineers Group on 16th October, 1946,† I am confident that you will understand my decision to omit A.C. references almost entirely from the present paper. Hand-operated control gear has been omitted, as also have electro-mechanical brakes. Special control schemes, such as automatic roller's and catcher's tables, pre-set screw-downs, sequence-interlocked rod-mill auxiliaries, and blast-furnace control, have all been omitted, as they may well form the basis of special papers in the future.

Mr. **R. A. Lake** (Lancashire Steel Corporation, Ltd.): On p. 363 of the paper, it is stated: "The separate inductance bank is unnecessary for the standard contactor panels which control racks, skids, pull-across, screw-down, and manipulators, as the starting period required is very brief"; and on p. 366 there is the statement: "Three resistance contactors are standard practice for the general run of auxiliary drives, including skids, roller tables, manipulators, and so forth."

We had a 40-h.p. motor, driving a roller table, to accelerate, and clearly to accelerate it up to the point at which the motor is connected right across the line, which is about 70% of full-load speed, one has only, with that system, about 2 or $2_{\frac{1}{2}}$ sec, because the plugging contactor closes directly after the line contactor. The horse-power required from the motor in that instance is too great during the contactor-accelerating period to ensure good commutation since the WR^2 of motor and rollers is over 40,000 lb/ft^2. It has been our experience that a contactor-acceleration period of 4 to 5 sec gives better results.

Perhaps we are under-motored. Nevertheless, if one gives the motor a 4 to 5-sec period for contactor

* *Journal of The Iron and Steel Institute*, 1948, vol. 158, March, pp. 357–375.

† *Journal of The Iron and Steel Institute*, 1947, vol. 155, February, pp. 271–288.

acceleration, it will do the job, whereas if one tries to do it with 2 sec, it will not.

I was very interested in Mr. West's supple-contact auxiliary switch on interlocked contactors, and I should be interested to know whether this is going to supersede the bar wiping on two bronze fingers, to which we have been accustomed.

With regard to mechanical interlocks, wear takes place which makes it possible for the two outer contactors to close simultaneously. However, normally the two pairs of reversing contactors on the D.C. panel are so arranged that the coils of forward and back contactors are not both energized at the same time.

Mr. **R. A. West** : On these mill contactors we rely entirely upon the mechanical interlock, and we do not double interlock unless there is a very special reason for it. I should say that on 90% of mill contactor gear there is no electrical interlock at all, because the mechanical interlock is 100% efficient.

Mr. **R. A. Lake** : I do not want to pursue this point, but in the steelworks we do not often get both forward and reverse contactors energized at the same time. If we did, we should get trouble more often, because the mechanical interlock is not, if you test it, always completely interlocking with the outer contactors of the two pairs.

With regard to Mr. West's remarks on 50/50 compound motors, we have many auxiliaries driven by compound motors of more or less 50/50 shunt and series. I believe that we would be better off with series motors on all of them. The only possible exception was a roller table with only six rollers of cast steel, entirely on roller bearings and with a closed gearbox, everything being apparently well lubricated. The compound motor permitted a rise of speed of 25% above the nameplate speed of the motor. A speed–load curve on this table showed that even with a plain-series motor, speed would not have risen more than about 50%. I do not think that is anything to be very frightened of. The greater torque per ampère of the series motor seems to me to outweigh the odd occasion when it is a little slow in coming to rest because the equipment driven by the series motor has reached a slightly higher speed. To obtain the full benefit from the series motor characteristic, however, a somewhat greater gear-reduction ratio is required than that for the compound machine.

One of the things that helps to limit the final running speed is that the speed–load characteristic is not entirely a straight line. There is a noticeable deviation with a roller-bearing table, because I think windage and oil churning play an appreciable part in the so-called "friction" load. In cases which I have observed, the characteristic between load and speed has a relationship of the approximate form of $y = ax^{1\cdot14}$. Between zero and the full nameplate speed that is not an appreciable deviation from a straight line, but in the higher speeds it does assist quite noticeably in limiting the speed of the table when driven with a plain-series motor.

It seems to me that plugging control is altogether superior to dynamic braking where there is an operator, because the braking torque is maintained right down to zero speed. I know that some mill tables, etc., are provided with dynamic braking, and I should be glad to know why.

Mr. **R. A. West** : I heartily endorse Mr. Lake's view against dynamic braking for a shunt motor or a light-series compound-shunt motor on mill tables. I think plug braking is the correct choice where there is an operator and braking does not have to be done automatically.

I like Mr. Lake's formula $y = ax^{1\cdot14}$. It corroborates what I have found on crane hoists and so on.

I would like to refer to Mr. Russell Taylor the question of roller interlocks on contactors.

Mr. **J. Russell Taylor** (Igranic Electric Co., Ltd.) : It is our intention to supersede the wiping type of interlock by the roller type of interlock. We have been experimenting with the roller type having supple contacts for about seven or eight years, and we have performed millions of operations with them. We have quite a number in service, and a great number are just going into service.

In connection with the mechanical interlocks between reversing contactors, we have also developed a wheel interlock, instead of the old type having two swinging catches which used to catch occasionally when they should not. The wheel interlock is extremely simple, and gives a rather better mechanical interlock than the old one. This is also being taken into service with our equipment.

With regard to Mr. Lake's point about electrical and mechanical interlocking, I think it is generally agreed that when plugging is to take place the change-over should occur as quickly as possible. A mechanical interlock, if it is well designed, gives a quicker change-over than a cross-electrical interlock.

Mr. **R. A. West** : The last point in Mr. Lake's remarks to which I wish to refer concerns the 40-h.p. roller-table drive and the 4 sec. total acceleration. It is not every drive that has to reverse quickly, but I.T.L. was developed for the quick-reversing drive. If in certain instances you want a slower rate of acceleration, or one more accelerating contactor, we should be delighted to provide it. The standard job, which has only two accelerators, is quite all right in most cases, and in 99 cases out of 100 with series motors. When you have a 50/50 motor, you must have a bit more time, and we can certainly give it to you by the CondITLe or condenser time lag system. Incidentally, we can get extra time—about 3 sec. per contactor—on I.T.L. by putting in two inductances ; they are, however, extremely expensive.

I feel that if Mr. Lake's drive was to reverse quickly, it should have had a 60-h.p. or 75-h.p. motor. It is only because the job does not require to reverse very quickly that it is quite all right to use a 40-h.p. motor with slow acceleration.

Mr. **J. Russell-Taylor** : We have known for many years that, during the starting period, a compound-wound motor does not give the extra torque per ampère that would be expected. If one winding of a transformer is switched on there is an interaction between windings, and the windings of a compound-wound motor behave in the same way. What is not generally known is the extent of this interaction in the case of the motor. I have asked many motor manufacturers for this information but have always drawn a blank. Last week I had tests made to find out what happened.

Series turns were added to a 10-h.p. shunt-wound motor in the test room. The motor was driven at a constant speed with the shunt-field ampère-turns reduced by the amount of the series-field ampère-turns considered as full load. The armature was connected to the oscillograph. Twice full-load current was switched on through the series winding and the armature e.m.f. rose to a new value. The time to rise was about 0·4 sec. No more tests could be made because the motor was required for routine purposes.

The investigations were transferred to the laboratory, where a magnetic circuit was set up equivalent to a motor field system. Oscillograms were taken of the current in both the shunt and series windings. Tests were carried out for a motor having 25% shunt and 75% series

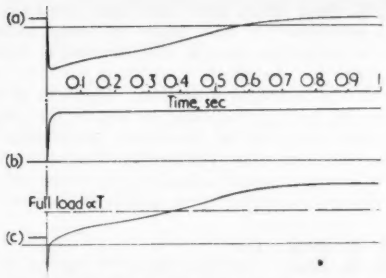


Fig. A—Curves for stalled motor: (*a*) Shunt αT 25%; (*b*) Series αT 75%; (*c*) Passing twice full-load current through series field. (Field represented by size *C* inductor with $\frac{1}{8}$-in air gap. Shunt coil 14150*T*, 0·9α, 359Ω across 32 V. Shunt *T* 12%. Series coil wound over shunt 74*T* 115α with series resistance across 220 V)

ampère-turns at full load, and also for a 50/50 motor. The oscillograms were traced to a scale of ampère-turns and are reproduced here (Figs. A and B).

In these figures, the top curve shows shunt-field ampère-turns, the middle curve series ampère-turns and the bottom curve is the algebraic sum. This last curve shows the active ampère-turns. Figure A represents a 25/75 motor stalled, and it is evident that even full-field ampère-turns are not developed till 0·4 sec has elapsed and complete excitation is delayed for about 0·8 sec. Figure B represents a 50/50 motor with the starting current dropping from twice full-load to full-load value in about 0·75 sec. Here it is seen that full excitation does not occur in 1·2 sec. If a plain-shunt motor were used it would develop immediately the torque corresponding to the armature current. I am sure that these curves explain why the compound-wound motor is so sluggish at starting, and obviously the same effects occur during plugging.

Dynamic braking uses the shunt field only for excitation, consequently the motor must work with a weak field. With either plugging or dynamic braking it is found necessary to use low values of resistance in order to produce sufficient torque, and this results in excessive armature currents with consequent commutation troubles.

I am convinced that there are only two correct types of field winding for a mill motor—plain-series, or (as nearly as possible) plain-shunt.

I hope that the motor manufacturers will now investigate the behaviour, during starting, of compound-wound motors, and give transient torque curves for the standard range and windings of mill motors.

Mr. **H. Rayner** (Contactor Switchgear, Ltd.): Has Mr. West investigated the possibility of straight-butt contact on the contactor tip, without roll or wipe, with a much heavier spring pressure than is normal at the present time? I believe this has been found to have a much longer life and is a better mechanical job altogether. It does away with contact bounce, which tends partly to weld contacts and certainly to burn them away at two or three times the normal rate.

I agree also on the matter of the efficacy of blow-outs. I remember one contactor that we supplied which closed on 1000 amp at 400 V and then rose to 3000 amp in 4 sec. An alteration from 3 turns to 5 turns in the blow-out altered the life of the contact from 25,000 operations without replacement, to 75,000. I have a feeling that the supple contact will tend to wear and will get a

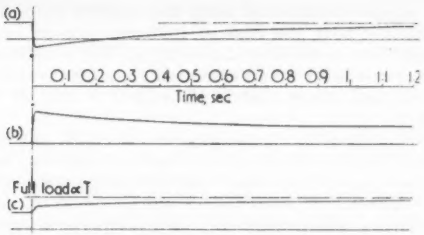


Fig. B—Curves for accelerating motor: (*a*) Shunt αT 50%; (*b*) Series αT 50%; (*c*) Passing twice full-load current through series field at switch-on. Shunt field and magnet as in Fig. 1. Series coil 34α at switch-on

sliding motion, which does tear contacts about. My own company has made many tests on auxiliary contacts, and we still like the upright type of plain-butt contact with silver faces, without any roll; we find these as efficacious as any type of contact we have tried. We have tested them to 20 million operations.

I agree that it is practically impossible to get dust-proofing through the use of a steel case, and that the open-type panel is probably the better proposition. I suggest that, instead of mounting the control gear on slabs of steel or slate, or one of the other materials, the bar-mounting construction, with steel bars suitably encased in insulated material, would be a better proposition for steelworks today. Our own experience is that these are less liable to trouble when there are flash-overs; there is more air all round them, which helps the ionization problem; and, if you do want to change a unit, it is a simple action and can be done quickly.

I should like briefly to touch on the matter of timing devices. I imagine that one or two of the diagrams in the paper which deal with diverter control are mentioned rather to emphasize the difficulties in the way of the man who wanted a longer delay than is given by the I.T.L., and so far as our experience goes, it needs a fair amount of adjustment to get the times that are really wanted. We think that a really well tried out and properly designed mechanical timing device is suitable for many of the applications in steelworks. Such devices are easy to get at, very easy to adjust, and if there is any trouble with them, after years of operation, they can be replaced in two or three minutes.

Mr. **R. A. West**: We use bar mountings for our contactor gear when necessary, particularly with cranes, but meanwhile we are sticking to slate for floor plant. Slate, properly bushed, seems to me to be the cheapest and simplest solution. The bar mounting is undoubtedly better for cranes.

With regard to very high pressure on butt contacts for contactors, we find that if we increase the pressure on ordinary copper contacts they wear out mechanically too quickly. The efficiency of our blow-out has reached the stage where we have got to watch the mechanical side, and not the electrical side, very carefully. I am sure many of you have seen the latest contactor, in which the arc is blown away from the copper altogether, and put on to a very heavy bronze casting which, being large, cools the arc and it goes out quickly. The bronze castings last for an extraordinarily long time. Of course, the copper wears electrically and mechanically, but we have to strike a balance. I think the balance we have struck is right. Possibly Mr. Rayner, when he mentioned this point, was thinking of one of those special alloys which are mechanically extremely sound. We have had some experience with them under rated normal pressures in the same contactor sizes on spot-welding, which is a

very severe destructive duty for contact tips. It is so destructive that the cost of replacing copper is really a main item in welding of that type. We have tried out these special alloys and although they last better, they cost so much more that in the end it is cheaper to use copper.

With regard to auxiliary contacts, I gather Mr. Rayner is in favour of a good sound vertical-butt contact that does not slide at all. I agree with the vertical direction. These new contacts of ours are vertical, so that they do not collect dust. If you look at one of these butt contacts you would say there is no rolling slide ; you cannot see it properly unless you examine it closely, but there is a minute spring in the action. We find on a failure test that these contacts fail about once or twice per million times, compared with as many as twenty failures with the solid-butt type.

Mr. **J. Russell Taylor** : Mr. Rayner talked about a well-designed clockwork timer. We have been looking for that for many years. During the war we were condemned to supply clockwork timers to the Admiralty. We bought them from several places, all of them guaranteed perfect, and we found that we had to strip every one, true up the bearings, clean up the teeth of the gears, and reassemble ; then we gave them a long run-in before we could use them. I should very much like to know how Mr. Rayner has managed to get a workable clockwork timer. To be certain that a clockwork timer will work, every tooth combination at starting must be tried and this takes much too long for commercial purposes. While they may run all right once the eddy drag, air vane, or escapement has started, the difficulty is always to be sure that the train will start. I think that the purely electrical scheme, using a solid piece of apparatus, has advantages.

Mr. **H. Rayner** : It seems to me that Mr. Russell Taylor has been trying to use a fair amount of energy on some very small teeth. What one needs to do is to put a very small amount of energy in a spring to operate this timing device, and then one does not wear out the teeth. We have had these timing devices on welders which have been operated for four years. A resistance welder operates a lot of times in four years. Mr. Russell Taylor also said that he had to run-in these timing devices. That is one of the secrets—to run them in for 24 or 48 hr, and then take them completely to pieces, after which they are a really practical and proper job. You must not try to drag a lot of little teeth with a hefty magnet. You must just store energy in the spring and then let it fade away with light power.

I agree about open-type contactor gear on cranes. I should think that many of those present have a fair amount of influence with the people who make cranes, and the more they can do in getting open-type contactors in separate cabins, the better it will be, both from the maintenance point of view and the operation of the gear.

Mr. **R. A. West** : There is one point I would like to make about the butt contact for the auxiliary circuits. We were intending to use a plain-strike butt contact for this purpose. It was a small mechanism operated by a roller interlock. We were prepared to go into production with that interlock in about 1940, but Mr. Russell Taylor decided that the old wiping type of interlock, where the bar of the contact comes up and wipes two brass fingers, had given such a good account of itself for nearly half a century that it should not be superseded unless a great deal of pains had been taken to compare results. He then hit on the idea of just changing this plain-strike interlock into the supple movement. As a result of tests, we decided that that was the thing to do.

Mr. **F. N. Bool** (Park Gate Iron and Steel Co., Ltd.) : There is reference in the paper to crane safety-limit switches arranged to reverse the armature connections with respect to the field, and thus achieve dynamic braking in the hoisting direction. Mention is made of such a switch being illustrated in Fig. 8, but the switch shown there seems to be the usual shunt-limit switch. A limit switch designed to perform the functions described would be a very useful addition to crane equipment. Is it of the direct-acting type, and does it carry the full current of the motor ?

Mr. **R. A. West** : Yes.

Mr. **F. N. Bool** : In the event of operation, is the dynamic braking loop restored for lowering ?

Mr. **R. A. West** : As soon as the limit switch re-sets, it is restored. When the limit switch trips, if you want to lower again you simply reverse the master-switch handle. When the limit switch re-sets, as it will do automatically with the lowering of the crane hook, the normal conditions are restored.

Mr. **F. N. Bool** : I was wondering about the possibility of inefficiency of the brake having caused the overwind, and whether the reversion to dynamic lowering conditions is achieved by the controller, or whether the switch is the direct-acting type and the motion of the gear re-sets the switch.

Mr. **R. A. West** : The limit switch trips by mechanical action, but fortunately, owing to the arrangement of the circuits, you can back out of that by simply reversing the controller handle. The hook then lowers rather slowly, and when it has done about one foot, the switch re-sets and conditions return to normal.

Mr. **F. N. Bool** : Even in the case of a simple series control ?

Mr. **R. A. West** : The Palmer limit switch works equally well on cranes equipped with a load brake or a symmetrical reversing control, but we use different connections to get the same result.

Mr. **F. N. Bool** : The switch appears to be of value in the case of the older-type cranes which do not have the panel-dynamic lowering. If it could be adapted to an ordinary series symmetrical control, it would appear to have special virtues.

Mr. **R. A. West** : I do not see that it has any more virtues than, say, a shunt-limit switch. Of course, it has its own inherent virtues, but as applied to a plain reversing control on a crane hoist, I am not clear.

Mr. **F. N. Bool** : Perhaps I might give an instance of what can happen in a shop that deals with the renovation of steel ladles. A crane has to pick up a ladle high enough to clear other ladles in the shop. That involves bringing it within an inch or two of the crane girder. On one occasion, when the man came to switch off, or the shunt-limit switch operated, whichever was the case at the time, unfortunately the key came out of the brake drum, which was of the overhung type, and the man had no control whatever. Due to the mechanized brake being ineffective the load raced to the ground and serious damage was done to the crane. How would this device have been of service in such a case ?

Mr. **R. A. West** : In such a case the Palmer limit switch would perform the dynamic braking in the hoisting direction and stop the crane regardless of whether the mechanical brake had failed or not. I have made tests. On the average 40-feet-a-minute steelworks' hoist the stopping distance of a Palmer limit switch alone—*i.e.*, going up at full speed with an empty hook, and the motor doing about $1\frac{3}{4}$-times full speed, and nothing to stop it, is about 8 in ; with the switch plus the series brake the distance is about 6 in. With a motor of 70 h.p. or upwards, you can actually see the Palmer switch reducing the speed of the pulley while the brake

is thinking about coming on. If the brake is out of action, as stated by Mr. Bool, the Palmer switch will prevent any damage by overwinding, but it cannot stop a load from falling.

Mr. **F. N. Bool**: I should imagine that the direct-operated type of dynamic braking is of the single-stage order, and therefore must involve heavy currents, but this may be permissible if the alternative is serious overwinding.

Mr. **R. A. West**: It is better still to have a shunt switch fitted for normal purposes and leave the Palmer limit switch as a back-up behind it.

Mr. **F. N. Bool**: Another method might be to have a hand re-set.

Mr. **R. A. West**: That is a good way out, too.

Mr. **F. N. Bool**: There is a field for time-limit devices other than I.T.L. for use on odd jobs about the works. Our experience of the pneumatic-diaphragm timer has not been very good. The time period increased: instead of remaining constant at 15 sec, we observed, in the course of a week, that it was creeping up to 80 sec.

Mr. **R. A. West**: I have found in blast-furnaces that dust gets in, so we now fit a snuffbox air-filter as standard on the diaphragm timer. It is not normally used, but it is available, and if anybody is having trouble, a piece of cotton wool can be inserted to filter the air. The diaphragm may be changed at very small cost for one with a snuffbox on it, or the side of the existing one may be drilled and a grease lubricator put in instead. It may be that you are trying to get too much time out of it. It is not really meant for more than 7½ sec.

Mr. **F. N. Bool**: I have suspected that dust was the cause of the trouble. We tried to enclose the mechanism, but we have not had much success. I tried it also in connection with a current-limit roller-gear panel, trying to introduce a little timing in effect, and the result there was that the whole thing collapsed after about the 137,000th operation, which represented 13 days' work.

Mr. **R. A. West**: I think that is really the answer in a nutshell. It really is not meant for very heavy duty like that. There are other timers. What do you use as a rated maximum with your clockwork timers, Mr. Rayner?

Mr. **H. Rayner**: We have various forms up to 20 sec. On one train of gears we have one that goes up to half-an-hour.

Mr. **R. A. West**: What would the accuracy be on half-an-hour—plus and minus 5%?

Mr. **H. Rayner**: We should not say more than 10%.

Mr. **R. A. West**: Half-an-hour is a long time to get accurately.

Mr. **H. Rayner**: I am talking more of the timers up to the order of 20 sec.

Mr. **R. A. West**: Is that what you want, Mr. Bool?

Mr. **F. N. Bool**: Yes, not longer. I would also like to lay hands on one of the order of half-a-second or so. In certain parts of the works we have current-limit control. It is not at the moment convenient to change all these to I.T.L. Everyone here will know the trouble that goes with current-limit control. It was in an effort to have some supervisory control imposed on this current-limit control that induced me to look for a suitable short-time timer.

Mr. **R. A. West**: What you want is a little thing in a box about 2 ft by 2 ft by 10 in containing the necessary equipment to give something like I.T.L. timing for three or four contactors.

Mr. **F. N. Bool**: That would be the ideal.

Mr. **R. A. West**: Are they very big contactors?

Mr. **F. N. Bool**: Yes.

Mr. **R. A. West**: I mean 400 amp. I should almost think that, if you were dealing with series motors, you could couple them in sequence and get enough time out of each switch. Returning to the pneumatic timer, however, it is not really meant for such frequent duties as that, and if anybody asks for it we usually put in a condenser timer nowadays. With this we can get 20 sec, if we want to do so, absolutely consistently.

Mr. **A. A. L. Bentall** (Metropolitan-Vickers Electrical Co., Ltd.): Although the author has been concerned mainly with methods of controlling D.C. motors by means of contactors, it will be of interest to consider some of the more modern and refined methods which are coming into increasing use.

War-time developments of servo-mechanisms are now leading to progressively wider industrial applications of closed-cycle control systems. These may sometimes involve the use of electronics, but can often be carried out by means of other types of equipment, such as the metadyne (a special type of D.C. exciter with an extremely high sensitivity), or magnetic amplifier (a piece of static equipment consisting only of transductors, *i.e.*, saturable core reactors, and metal, usually selenium, rectifiers).

For drives up to the order of say, 15 or 20 h.p., it is possible to supply the D.C. motor direct from the output of the metadyne generator; for larger equipments, it is usual to use a modified form of Ward-Leonard control, in which the main generator is excited from either the metadyne or transductor, instead of from a constant potential supply via contactors and resistances.

The introduction of this type of control system immediately opens up new possibilities, by the provision of smooth, stepless control, with facilities for introducing one or more overriding controls. Thus, for the most common case of speed control, a signal is derived from the back e.m.f. of the motor and compared with the reference set by the operator's control. If there is any discrepancy between the two, the error is used to adjust the metadyne or transductor output in such a way as to restore the required condition. In many cases, steel-mill auxiliaries require to be repeatedly accelerated and retarded, and at the maximum rate that the electrical machinery will stand. By the introduction of continuous overriding current control, it is possible to accelerate at the highest permissible rate, due account being taken automatically for variations in the load. In like manner, overriding acceleration control is possible, and in such a case, the motor will accelerate at any desired rate up to the speed called for by the controller, and it will maintain this speed, substantially independent of the load. Similarly, for deceleration, the motor will slow down, stop, or reverse as required, with either torque or deceleration overriding limit control. In this case the braking effect is superior to both plugging and dynamic braking, as the reverse torque is maintained from full speed practically down to standstill, and the kinetic energy is returned to the line as electrical power.

In some applications at present, speed control of an object is provided to enable the operator to control its position (*e.g.*, the tilting of a ladle), whereas the provision of a coarse-position control would give much greater ease of handling. The metadyne, because of its quick response and high sensitivity, is eminently suitable for such a control and enables heavy loads to be positioned rapidly in response to the movement of a light control handle. For more accurate position controls, the metadyne may be used in conjunction with either a magnetic or electronic amplifier—such an arrangement is being applied to screw-down control.

Another example of a position control is the automatic regulation of the current in electric-arc furnaces, where the positions of the individual electrodes are continuously

adjusted to maintain the load substantially constant. In this case the metadyne can provide sufficient amplification in itself, without the addition of transductor or electronic control.

For some drives, it is required to maintain the torque produced by a motor, or the tension in some material, at any pre-set value. In these cases the metadyne is used to regulate the armature current of the main motor and maintain it constant under steady running conditions. This system is of particular importance in the case of reeling drives, where an additional feature required is compensation for the inertia of the reel and reel motor during acceleration and retardation—achieved very conveniently by means of an appropriate derivative signal applied to an auxiliary winding of the metadyne.

Some steel-mill equipments require two or more motors to run in step with each other, or at a given slip between certain machines (*e.g.*, synchronization of roller tables, upcoilers, or flying shears with the speed of the mill). Here, metadynes may be used to control the fields of the various motors and thus to trim the speeds to the required values, or, alternatively, they may adjust the field strength of Ward-Leonard generators to control the speeds by armature voltage-control. Again appropriate compensation may be introduced to ensure synchronization during acceleration and deceleration, as well as at steady running speeds and under varying loads.

In order to decide which particular type of control system should be used, it is necessary to take into account the overall requirements of the scheme, including the accuracy, consistency, and speed of response that are necessary. In special cases the use of electronic control may be desirable, but often one or other of the systems to which brief reference has been made, will prove quite adequate.

Mr. **D. Pearson** (Steel, Peech and Tozer, Ltd.): We are using Palmer limit switches extensively, and we have almost decided to standardize on them. In the event of the switch tripping with full load or overload on the hook and the switch failing to re-set, what speed would the crane get up to ? I am afraid the lowering speed would be excessive.

Mr. **R. A. West**: When it is tripped with full load, the thing will go down too fast, but we have a circuit to stop that. It is not very often called for but we are quite prepared to put forward for consideration the necessary device that prevents that running-away effect. I think it is safe to say that in most cases Palmer limit switches operate at high speed with nothing on the hook, but there are low headroom buildings where one may get the condition which Mr. Pearson described. Even so, the distance which the job would have to run would not be very far, but if it were a ladle it might be a serious matter.

Mr. **J. H. Butler** (Stanton Ironworks Co., Ltd.): The tendency nowadays seems to be for the amount of power available at an iron and steel works' plant to be on an ever-increasing scale. With the stations that are now being contemplated, it is not unlikely that something like 6000 or 7000 kW of D.C. power will be available close to the mill auxiliaries. I do not dispute that the final control gear for individual drives, and certainly the main station switchgear, are quite adequate to deal with faults that are likely to develop, but there seems to be one rather weak link in the chain—unless the designers have altered their ideas during the last two years. I am referring to the final distribution gear as applied to the mill auxiliaries operating on about 500 V D.C. The experience I have had is that in many instances the gear has been designed very compactly, and is rather prone to give rise to serious disintegration on any attempt to clear what is not a very uncommon occurrence, *viz.*, practically a dead short circuit across the D.C. supply due to some fault on an auxiliary drive. I think that the designers should pay particular attention to these apparently unimportant switches that find their way into the circuit between the main station switchgear and the final controllers.

Mr. West mentioned an instance of a breast-roller drive having its 150-h.p. D.C. motor switched straight on. How long has that been operating, and what is the experience with regard to wear and performance at the motor commutator ?

Mr. **R. A. West**: We fit most of our mill-type panels as standard with English Electric HRC main fuses, but there are really two ranges of panels available—those with, and those without—because, according to which part of the works you are working in, there is a very big drop in voltage in the event of a sudden short circuit, and it is really a matter of opinion on the possible financial risk of blowing up the contactor compared with the investment of dead capital in very many HRC main fuses. That is a job for the installation engineer to decide for himself. If he likes to have HRC main fuses on each mill panel, they are there to be had.

With regard to the direct-on breast roller, I explained in the paper that a standard panel was put in with this breast roller, but that as a matter of interest we experimented with it by reducing the resistances, and so on, until we direct-switched it to see what would be the result. It is still working with a panel. It is a compound motor and my own feeling is that had it been a series motor, it could have been direct-switched from the beginning and would still be working like a nice series motor, possibly not with a blue shining commutator, but at least with one that only needed to be repaired once in two years. After all, there are many kinds of grubby-looking commutators that go on like that for years without attention.

I must apologise for the omission of the Palmer limit switch from the diagram in the paper.

Dr. **L. Bramley** (British Iron and Steel Research Association): Mr. West is quite right in drawing attention to the evils of oxide films forming on copper and silver contacts. On the question of using silver for contacts, I have had a little experience of this. Contacts carrying an appreciable current will heat up, causing the oxide to disappear, but this is not true for very small contacts, which do not heat up. Those who are interested in relays will agree that silver contacts for relays and very small current-carrying contacts are not the complete answer. Mr. West tacitly admits that, because on p. 360 of the paper he states that on the supple contact he is getting failures amounting to only one or two per million operations. I feel that that is too many. The failures can be completely eradicated by the use of rhodium, which is now commercially available for contact use. I do not think it has ever been used in steelworks. In my experience, the troubles with silver contacts are very greatly accentuated by dirty and sulphurous atmospheres, and if rhodium contacts are used and are mounted vertically, I think they will be found to be a very great improvement. I am speaking only of contacts for very small currents.

The question of disconnecting a motor on overload is one of great interest to the British Iron and Steel Research Association, because we are preparing a specification for steelworks' cranes, and I would like to have Mr. West's opinion as to how much recourse we should have to inverse time delays in protecting a motor. A common system is to use inverse time delays on each motion, but to have instantaneous tripping when the whole crane is protected. Then, in the event

of a bad short circuit, the main-circuit breaker will come out instantaneously. The system appears to us to have weaknesses, and I should like to know whether Mr. West feels that protection could be improved by the use of better discrimination.

It appears that there is no thoroughly reliable inverse time delay available. In nine cases out of ten the oil dashpot is used, and when the oil has not been splashed out of the pot, the crane driver unscrews the dashpot and dips his finger in the oil in order to lubricate something. We have looked at other devices, notably a pneumatic device, for producing inverse time delays. The pneumatic device seems to have some good points, but the one I have seen has no indication as to where it is set. If one wishes to set it at, say, 5 sec, a little screw locks it, but there is no indication ; you have to use a stop-watch to find out where it is. In view of the marked simplicity and apparent reliability of the pneumatic inverse time delay element, which I have heard praised in steelworks when all other devices have been decried, I feel that the addition of a small device which would show roughly where it was set would be a great advantage.

On p. 365, Mr. West starts off by saying : " If it were practicable to analyse each cross-traverse drive as it occurs, it would be found that many of them could be provided with adequate control if the panel had only one plugging contactor and two accelerators." By ingenious arguments we are led down to the bottom of the page, through two, three and four, to the final sentence which states : " It is, therefore, obvious that one might as well adopt five " (contactors). I think that five would appear to be too many.

Mr. **R. A. West** : It looks rather strange when you compare two accelerating contactors with the five mentioned at the end, but what I mean is that one plugging and two accelerating contactors, making three, are too few on certain occasions, and that therefore four is a safe number ; but four do not fit in well with standardized panel layouts, and therefore one might as well have five.

Dr. **L. Bramley** : The feeling I have is that it seems to allow quite a lot of latitude, and it seems a rather regrettable waste when three would be enough.

Mr. **R. A. West** : From that point of view, I think it is well worth going into the question of what can be done to standardize on three.

Dr. **L. Bramley** : On D.C. cranes light-hook speeds are very high, but the production people are calling for still higher speeds. Mr. West points out that ordinary cranes are running at 200%, and quenching cranes up to 250% of geared speed. It seems to me that the mill-type motor would do more than 250% of geared speed. Does Mr. West agree that the risk of the burst brake drum is the limiting factor. If it is not, what is the limiting factor, and what possibility is there of going up to still higher speeds ? In particular, if quenching cranes can be run at 250%, why should we not run other cranes at 250% ? I am sure the production people would welcome even an additional 50%.

Throughout the paper, Mr. West deals with " dynamic braking." I feel that the term should be " rheostatic braking." The British Standards list of terms shows rheostatic braking to be the acceptable term, and dynamic braking to be the one that should be avoided.

Mr. **R. A. West** : I think that precision in engineering terms should be increased all the time, and the term " dynamic braking " is a little nebulous. I use dynamic braking to differentiate between braking in which the resistances only take back the flywheel energy of the motor, compared with plugging, in which you have to absorb in the resistance not only the flywheel energy of the motor, but a whole lot of extra energy from the lines. That really is the difference, but I think Dr. Bramley is quite right.

I assume Dr. Bramley refers to lowering speeds, as their problems are more difficult than for hoisting.

The limiting speeds for cranes are economic. I think that with a mill-type motor used for a hoist, there is no reason whatever why a maximum speed of 200% light and 250% with full load should not be adopted as a standard if you want to do so ; but who wants to lower a full load faster than a light hook ? By all means let the light hook go down at 200% speed, but I cannot see any object in creating dangerously high speeds with full loads, except for quenching. Sooner than have special motors and devices that could do 300% or 350%, it would be simpler to put up the geared speed in the same ratio.

With regard to overload protection, there could be a lot of improvement. The devices that we use, and I think those used by most other makers, are distinctly crude, and definitely are not instruments. We require a thermal integrator, but I think nobody has produced a steelworks version that will simply trip when the motor has reached its limit of 75° C as normal running temperature. I think that the crude little relays that we do use just give that protection that looks after the ordinary emergency. The mill-type motor can cater for all ordinary loads, and the time lag allows a reasonably low current setting for an emergency.

Mr. **J. Russell Taylor** : I think there is quite a lot in the rhodium plating of silver contacts. Mr. West said in the paper that there were one or two failures per million operations ; that was because it has always been our tendency to keep our statements down, rather than to say that everything is perfect. We did not have one failure in over three million operations in our tests.

The history of dynamic lowering is that crane hoists were originally of the plain reversing type used in conjunction with " mechanical load brakes." These brakes gave trouble, and in order to enable them to be dispensed with an electrical scheme was developed known as rheostatic braking. This control connected the motor as a series generator and to an adjustable resistance, and permitted the load to overhaul the motor at controlled speeds. The hook would not descend light, but usually light load notches were provided to drive the hook down. If the controller was used on these notches with full load on the hook there was no retardation, and the dangerous speeds could occur. The late Mr. Mortenson of Cutler-Hammer Inc., designed a controller where the rheostatic braking circuit was connected to the supply through a resistance, so that a drive-down torque was obtained with light loads, and a retarding torque with heavy loads. The Cutler-Hammer company registered the trade name " Dynamic Lowering " for this type of control. Similar controllers were designed by competitors to which they applied the name " Potentiometer Lowering."

The term " dynamic braking " probably came from the same source, and is taken to mean braking obtained by connecting the motor armature to a resistance, in contradistinction to mechanical braking by friction.

Mr. **F. W. White** (Allen West and Co., Ltd.) submitted the following written contribution : I would support the statement that mechanical timers offer more ready adjustment and wider range of timing than the inductive unit. On the other hand, the conventional escapements or gear-train mechanisms obtained from reputable sources have to be completely stripped and overhauled before inclusion with control gear, and even then, there

is the ever-present risk of dust entering the mechanism and affecting, or even stopping, operation.

The small series-wound universal motor, when limited in speed and applied voltage, is an exceptionally reliable piece of apparatus, and this has been adopted as the basis of a motor-operated timing unit. The motor drives through a single robust gear reduction on to a fabric-bakelite worm wheel carrying the moving contact system, and by a combination of variation of motor voltage, gear ratio, number of contacts and eddy-current braking, provides any timing from 0·5 to 20 sec per contactor, with any required percentages of current/time bias, according to load conditions. This single unit will control any number of contactors and is equally applicable to A.C. and D.C. drives, thus permitting a great measure of standardization.

I agree with the author that a little is as bad as a lot where dust is involved, and have found that slight wipe of contacts is essential in auxiliary interlock design. Even so, there are the mysterious failures, and here I have noted instances where an applied voltage of up to 1000 V has been necessary to break down the surface resistance. Close investigation, in these instances, has revealed failure due to cupric oxide at the point of contact and is due to the presence of copper as an impurity in commercial silver. Careful attention to contact profile and spring pressures during design will reduce the risk of failure due to this cause.

Description of New Plant

Ore-Dressing Laboratory at the United Steel Companies, Ltd.

Introduction

The United Steel Companies, Ltd., use Cumberland hematite ore, Frodingham ironstone, and Northants ironstone in their blast-furnaces, the first-named stone being smelted at Workington and the other two at Scunthorpe.

Some of the Cumberland hematite deposits contain barytes, and while such ores can be smelted in the blast-furnace, less slag would be required if the barytes could be eliminated beforehand. Such elimination would reduce the fuel consumption per ton of iron produced and also increase the make of the furnaces appreciably.

The Frodingham and Northants ironstones are blended to give a self-fluxing furnace burden, but their iron content is so low that more slag than iron is produced. If this slag volume could be, say, halved, the fuel consumption per ton of iron produced could be reduced considerably; moreover, the throughput of iron could be increased correspondingly.

As both problems present some novel features, it was decided to initiate an extensive programme of research to ascertain whether the barytes could be removed from the Cumberland ore, and whether the slag-forming constituents could be eliminated from the Frodingham and Northants ironstones. A suitably equipped ore-dressing laboratory has been installed at Swinden House, Rotherham, and work there will be supplemented by pilot work on magnetizing roasting at Scunthorpe, and on flotation (or agglomeration) tabling in Cumberland. These may form the subject of later articles.

The scheme of research to be carried out at Swinden House includes:

(*a*) Crushing, milling, grinding, and screening of ores to determine the optimum conditions for the liberation of the constituent minerals.

(*b*) Flotation tabling and froth flotation as means of separating the mineral constituents liberated by the above processes.

(*c*) Magnetic separation as a means of separating the constituents of roasted or unroasted ores.

In the Swinden House laboratory the equipment has been arranged for batch operation, and Fig. 1 shows a flow diagram of the various processes. Incoming run-of-mine ore may be passed through a jaw granulator, crushing rolls, or a multi-hammer mill (or any combination of these three machines) and the products passed over a double-deck vibrating

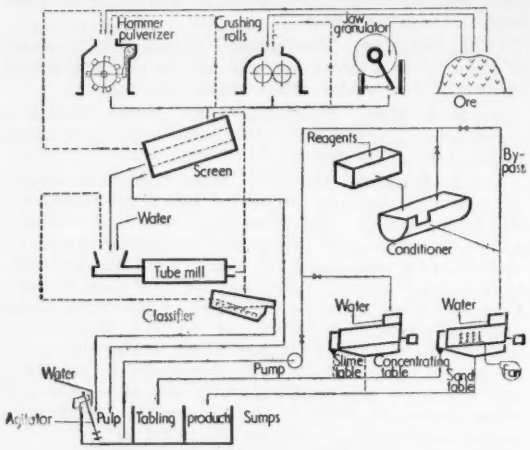


Fig. 1—Flow diagram

screen at any stage in this sequence. In each case the ore is fed to the machine by a vibrating feeder. The screen cloths are readily interchangeable so that a wide range of size fractions may be separated for examination.

Material from any of these initial stages can be fed to a tube mill for further reduction. The mill has four compartments, each of which may be charged with

balls, slugs, or rods, and can be operated wet or dry. In wet grinding the product is passed to a double-acting rake classifier so that the coarse particles may be separated for regrinding, both coarse and fine particles being collected in separate compartments of a sump.

Material in any of the sump compartments can be agitated by a stirrer and passed *via* a centrifugal rubber-lined pump either back to the tube mill or to concentrating tables. One of the tables is riffled for extremely fine particles ("slimes"), the other for coarse particles ("sands"). Material for the sand table may be passed direct to the table or conditioned in a horizontal paddle mixer before flotation tabling on the same table; in this case air is blown across the riffle from a system of pipes. Reagents are fed to the mixer from a four-compartment bucket feeder mounted over the mixer.

Auxiliary equipment in the laboratory includes a vibrating-sieve shaker for the mechanical grading of samples, using B.S.I. sieves, a disc grinder for the preparation of assay samples, and a hydrosizer for the preparation of froth-flotation samples. A small high-intensity magnetic separator will be installed shortly, primarily for use on unroasted ores.

In addition to the ore-dressing laboratory, an ore-chemistry laboratory has been set up in an adjacent building for the study of chemical aspects of ore concentration. The equipment of the ore-chemistry laboratory includes a Fagergren flotation cell arranged for batch operation.

BUILDINGS

The equipment is housed in a portion of an existing building 54 ft. long by 21 ft. 4 in. wide by 12 ft. 0 in. high (to the eaves), internal dimensions. Certain structural alterations have been carried out, including the provision of a new roof of steel construction with sufficient headroom for the installation of an overhead-runway hoist for the handling of materials. The machine foundations and flooring are of concrete construction.

Photographs of the building and equipment are shown in Figs. 2, 3, 4, and 5, and the layout of the plant is shown in Fig. 6.

PROCESSING EQUIPMENT

The major items of equipment installed in the laboratory are as follows:

(1) Edgar Allen 12 × 6-in. jaw granulator.
(2) Edgar Allen 18 × 12-in. high-speed crushing rolls.
(3) Edgar Allen No. 1 size multi-hammer pulverizer.
(4) Edgar Allen Allis Chalmers aero-vibrating double-deck screen.
(5) Edgar Allen 7 ft. 0-in. × 1 ft. 6-in. tube mill.
(6) Stokes 9-in. × 3 ft. 6-in. double-acting classifier.
(7) Vacseal rubber-lined grit pump.
(8) Holman horizontal paddle-type conditioner.
(9) Rotating-bucket-type reagent feeder.
(10) Holman James half-size vibrating sand table.
(11) Holman James half-size vibrating slime table.
(12) Sump with Kestner stirrer.
(13) Fan for sand table.
(14) Laboratory-type Fagergren froth-flotation machine.
(15) Vibrating sieve shaker.
(16) Micro-section grinding machine.
(17) Vaughan 10-cwt. capacity runway hoist and track.

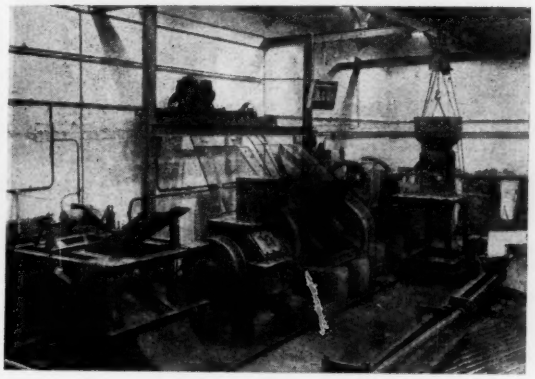


Fig. 2—General arrangement

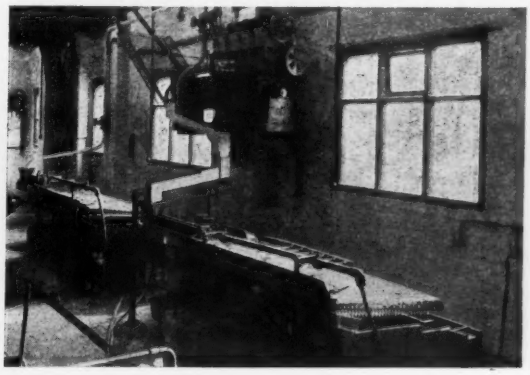


Fig. 3—Flotation tables

(18) Feeder trolley fitted with Sherwen 8 × 20-in. magnetic feeder.
(19) Feeding hoppers with bottom-discharge gates.
(20) Knapp and Bates 8-in. disc pulverizer.

The equipment will also include an electromagnetic separator, which is not yet installed.

Jaw Granulator

The jaw granulator, which provides a combined crushing and shearing action, has mouth dimensions of 12 in. × 6 in. at the top, and these dimensions therefore determine approximately the maximum sizes of materials which may be fed into the machine. The machine can be regulated to break the material down to $\frac{3}{4}$ in. or less, and is independently driven, at a speed of 260 r.p.m., by a 15-h.p. motor.

Crushing Rolls

The double-roll crusher has smooth rolls 18 in. in dia. by 12 in. long and is designed to give a size reduction of 4 to 1. One roll is carried in fixed bearings and the other roll has sliding bearings which allow adjustment of the roll centres to suit the desired product size. The machine is operated from a countershaft by one open and one crossed belt, each driving heavy flywheel pulleys to give the required contra-

direction of rotation of the rolls. The machine runs at a speed of 150 r.p.m. and is driven by a 15-h.p. motor.

Multi-Hammer Pulverizer

The multi-hammer pulverizer is independently driven by a 10-h.p. motor without any speed reduction, and runs at 1465 r.p.m. The hammers are mounted between spacer discs and are maintained in their outward position by centrifugal action. A hinged breaker plate with handwheel adjustment allows a certain amount of variation in the pulverized product and is also a means of taking up wear on the hammers and plate.

Double-Deck Vibrating Screen

The double-deck vibrating screen is a self-contained unit, complete with supporting structure, the screen size being 4 ft. 0 in. × 2 ft. 0 in. The material fed to the machine is subjected to a rapid vibrating motion produced by counter-weighted flywheels

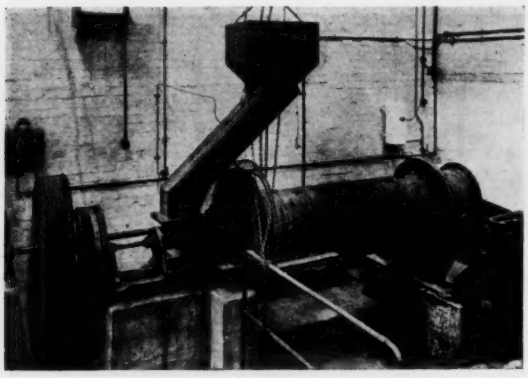


Fig. 4—Tube mill and classifier

running at 1730 r.p.m. and driven by a ½-h.p. motor. Screen cloths of various meshes appropriate to the required particle size are readily interchangeable, enamelled cloths being used for screening certain types of ores. The screen may be used for either wet or dry separation.

Tube Mill

The 7 ft. 0-in. × 1 ft. 6-in. tube mill is driven by a 12-h.p. motor. There are two intermediate speed reductions, giving a drum speed of 50 r.p.m. The tube mill is capable of being used for either wet or dry materials previously reduced in one or more of the preparatory mills. The mill may be divided into four compartments by the insertion of perforated diaphragms, each section being charged with cast alloy balls of graded sizes, or other grinding media. A screw-type feeder driven from the countershaft of the main drive is provided, and discharge of ground materials is effected either through a conical mouthpiece fitted concentrically to the end plate of the mill, or through a perforated end plate.

Classifier

A 9-in. × 3 ft. 6-in. double-acting rake-type classifier is employed to return oversize particles to the tube mill for further grinding. The classifier consists of an inclined tank with adjustable weirboard for the overflow of the fines, and two sets of moving rakes for propelling the oversize particles up the incline and, at the same time, maintaining the finer particles in suspension until they overflow. The movements of the beams carrying the rakes are derived from link motions driven by a ⅛-h.p. motor running at 925 r.p.m., four speeds being obtained by the provision of stepped **V**-rope pulleys.

Concentrating Tables

Holman James sand and slime concentrating tables are installed which facilitate the separation of particles of varying specific gravity and size. The process of separation depends upon vibration, tilt of deck, type of riffling, and fluidity of the pulp, the resultant constituents being led off and discarded or collected as desired. The sand table is used for treating fairly coarse materials, and the slime table deals with finely ground materials or slimes from the

Fig. 5—Ore chemical laboratory

initial classification. A feed distributor spreads a thin even sheet of pulp along a length of the upper edge of the deck, and a supply of town's water for diluting the pulp film is provided on each table. A multivane centrifugal fan capable of delivering 200 cu. ft. of air per minute at a pressure of 7 in. W.G. is provided for aerating the sand table. A differential vibration is imparted to the deck of each table by a vibrator which gives a diagonal thrust. The length of stroke of the vibrator can be varied, and reversal of the direction of rotation provides an entirely different set of stroke characteristics. The inclination of the deck can be regulated by a lever at the side of the table, and each table is independently driven by a 2¼-h.p. motor.

Sump

The tables are fed from an underground sump in the form of a steel tank, which is divided into three compartments. The feed consists of 20–30% of solids, maintained in aqueous suspension by the provision of a Kestner portable stirrer fitted with two 8-in. dia. stainless steel propellers running at 440 r.p.m. and driven by a 1-h.p. direct-coupled geared motor. The feed is pumped from the sump to the tables by a 2-in. Vacseal rubber-lined grit pump capable of delivering 50 gal./min. against a total head of 25 ft., and

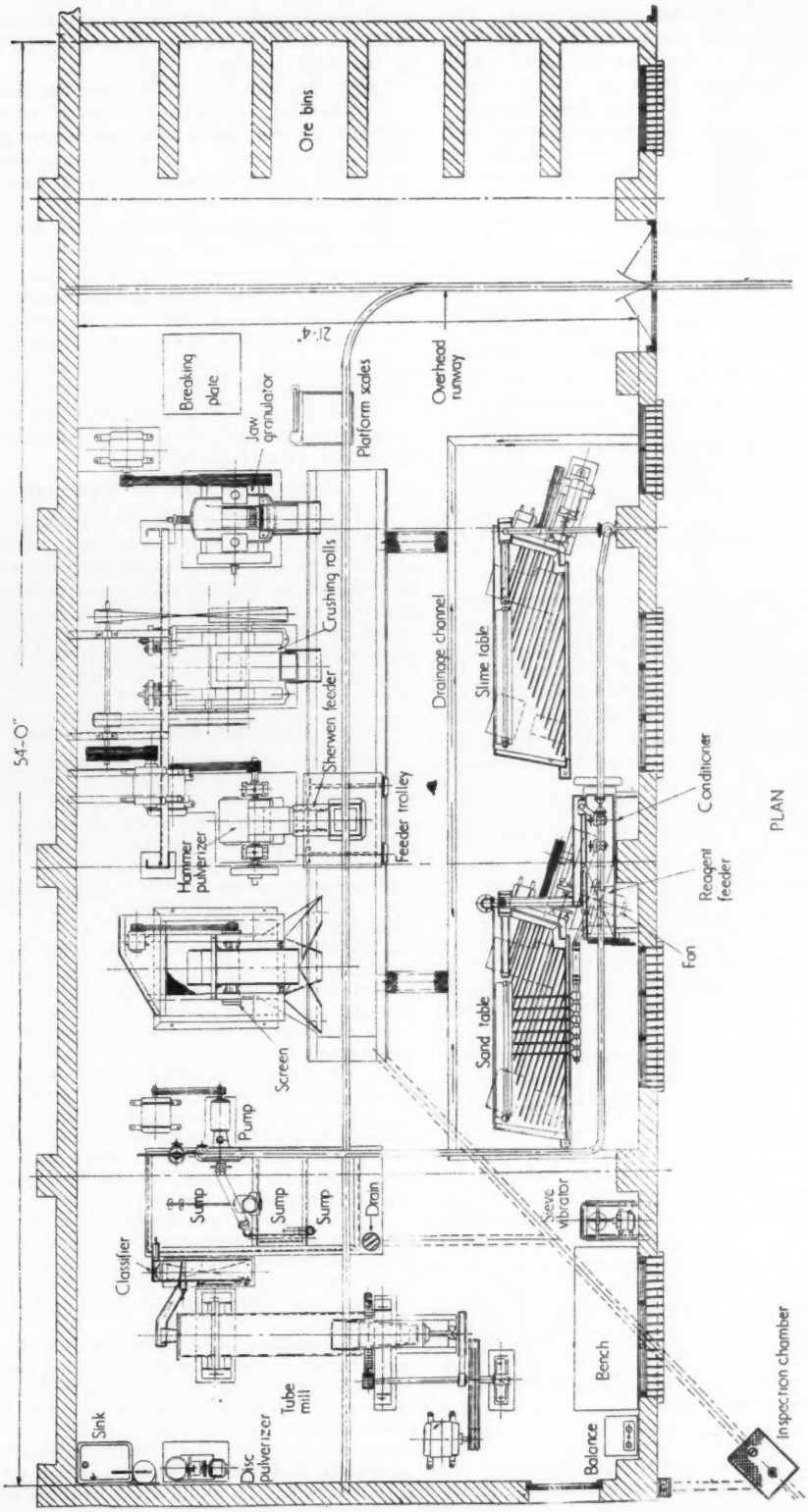


Fig. 6—General arrangement of ore-dressing laboratory. The machine guards are not shown

equipped with a hand-operated priming pump. The suction connection of the pump can be coupled by armoured flexible hose to fixed suction pipes, which enable pulp to be drawn from any of the three compartments of the tank. Delivery from the pump is effected through a pipework system equipped with diaphragm-type isolating valves, which enable the feed to be supplied direct to either table or *via* the conditioner to the sand table.

Conditioner and Reagent Feeder

The horizontal paddle-type conditioner is driven at 66 r.p.m. by a 5-h.p. motor, and the drive for the bucket-type reagent feeder is taken from the paddle shaft of the conditioner. The four compartments of the feeder allow of up to four different reagents being fed simultaneously, and the rate of feed from each compartment is infinitely variable from 0 to 5 gal./hr. The conditioner is provided in order to ensure adequate mixing of the feed and reagents which are added to assist the process of separation on the sand table.

The tabling products are discharged into collecting boxes or conveyed from the tables by flexible hoses to appropriate compartments of the sump.

Motors

All the electric motors driving the above equipment are of the squirrel-cage induction type, operating on 400-V., 3-phase, 50-cycles supply. The motors for the crushing and milling machines are controlled by star-delta starters, and other motors by push-button-type direct-on-line starters. The motors driving the screen, tables, and pulverizer are totally enclosed, the others being of the screen-protected type. **V**-rope drives are fitted in all cases, with the exception of the drive from the countershaft to the crushing rolls where contra-rotation of the rolls is effected by open end crossed flat belts.

MATERIAL-HANDLING EQUIPMENT

A 10-cwt. capacity hand-operated runway hoist is installed to facilitate the handling of materials, the runway track being suspended from the roof principals. A cantilever portion of the runway track extends into the yard to enable incoming materials to be unloaded direct from road vehicles. These materials are received in sealed cylindrical containers which are discharged into storage bins disposed along the end wall of the building adjacent to the main door. Materials for processing are dealt with in 5-cwt. batches and are loaded into feeding hoppers of the bottom-gate-discharge type which are handled by means of the runway hoist. The materials are fed to the crushers and screen at a controlled rate, which may be varied by a Sherwen 8 × 20-in. magnetic feeder mounted on a movable trolley running on a rail track. Suitable feed and delivery chutes serve the crushers and screen, the receiving hoppers which collect the crushed or screened materials being located in a pit between the rails of the trolley track. The tube mill is fed directly from a hopper suspended from the overhead-runway hoist.

SERVICES

Electric-power supplies of 400 V., three phase, 50 cycles and 230 V., single phase are available, and a small metal rectifier providing a direct-current supply of 3 amp. at 110 V. for the magnetic feeder is mounted on the feeder trolley.

Supplies of town's gas and water are also provided.

The heating installation consists of two Bratt Colbran luminous-panel overhead radiant gas heaters, fixed approximately 9 ft. above floor level, with a slightly downward inclination of the radiating surface; each heater has a rating of 24,000 B.Th.U. per hour.

The general lighting installation consists of 12 300-W. lamps in pendant fittings of the dispersal type, with glass visors, giving an intensity of illumination at the working plane of approximately 12 foot-candles. In addition there are two 300-W. lamps of the wall-mounting angle type fixed over the flotation tables to provide the additional intensity of illumination necessary for the close observation of the process.

Ventilation is provided by three 18-in. Robertson ventilators, complete with dampers fixed at intervals along the apex of the roof.

INSTALLATION OF EQUIPMENT

The selection and layout of plant, modifications to the building, and the design and construction of certain items of equipment, have been carried out by the staff of the department. In connection with the provision and installation of other items of equipment, assistance has been rendered by other branches of The United Steel Companies, Ltd.

Seventy-Five Years Ago

On Friday, 22nd August, 1873, the last day of excursions at the Institute's Special Summer Meeting at Liége, a party of about 150 visited M. d'Andrimont's coal works and workmen's establishments at Micheroux.

Under the guidance of M. d'Andrimont, the party first examined the buildings above ground, including the ventilating apparatus and the Hotel Louise. This hotel was built by M. d'Andrimont to provide living accommodation for the workmen.

After lunch the members descended to the workings. They put on the blue linen costume and the stiff leather hats of the miners and, provided with the Mueseler lamp, were lowered down the shaft. M. Henrotte, the engineer of the works, received them in a reception hall constructed at the base of the shaft, the walls of the hall being covered with porcelain and marble, and the roof of opaque glass. There wine was distributed. The visitors were next led through long galleries lined with bricks and lighted by gas, to a pulley, on which was an endless chain 7000 metres (7595 yards) long, employed to draw the small coal-laden wagons. The full wagons drew up the empty ones, and no steam or hydraulic power was used. The party also visited the Sidonic level and entered a wooden gallery, which brought them to some of the working faces. After an explanation of the working procedure by M. Henrotte, the members ascended, and refreshments were again provided.

Mr. James Kitson, jun., of the Monkbridge Iron Company, Leeds, proposed a last toast to M. d'Andrimont. In reply to the toast M. d'Andrimont said that whatever there was of interest at the Hazard had been copied from English models, and the debt which he had endeavoured to pay to Great Britain in receiving worthily his guests, had enriched him, as it had procured him friends to whom he would drink with his whole heart.

N E W S

ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Amendment to Bye-Laws

The Council gave formal notice, at the Autumn Meeting, 1948, of a proposal to amend Bye-Laws Nos. 3 and 21 at the Annual General Meeting in 1949.

The following letter has been circulated to all Members :

DEAR SIR,

Subscription Rates

The Council has reluctantly decided that, in view of the increased costs of all services and of the expanded activities of the Institute since the War, it is no longer possible to maintain the subscriptions of Members and Associates at the present rates, which have remained substantially unaltered since 1921. It has, therefore, been decided to make the following alterations, with effect from 1st January, 1949 :

(*a*) The Entrance Fee for new members will be abolished.

(*b*) The standard rate of subscription for Members will be £4 4*s*. per annum (reduced rate for members of the Institute of Metals, the Institution of Metallurgists, and/or certain societies overseas (listed below) £3 13*s*. 6*d*. per annum).

(*c*) The standard rate of subscription for Associates will be £1 15*s*. per annum (reduced rate for members of the Institute of Metals, the Institution of Metallurgists, and/or the affiliated local societies and certain societies overseas (listed below) £1 11*s*.).

(*d*) The maximum age for Associates will be reduced from 28 to 25. Associates over the age of 25 on 1st January, 1949, will remain Associates until they attain the age of 28. (The age limit for Associates resident in the U.S.A. and Canada who are members of the American Institute of Mining and Metallurgical Engineers will, in accordance with a reciprocal arrangement, remain as before.)

(*e*) Life Composition fees will be increased and the following rates will be payable :

Up to 29 years of age...	£70
From 30 to 39 years of age	£63
From 40 to 49 years of age	£56
From 50 to 59 years of age	£49
From 60 years of age and upwards ...	£42

The Council proposes, at the Autumn General Meeting in 1948, to give notice of the alterations of the Bye-Laws required to give effect to this decision, so that the necessary alterations may be made by Members at the Annual General Meeting in 1949 ; these alterations will then have to be submitted to the Privy Council for approval. The Council expresses the hope, however, that Members will be willing to pay the increased rates from 1st January, 1949, pending completion of these formalities.

Yours faithfully,

K. HEADLAM-MORLEY,
Secretary.

October, 1948.

Foreign Societies—Members and Associates who are members of any one of the following societies pay a reduced subscription :

American Institute of Mining and Metallurgical Engineers
American Iron and Steel Institute
American Society for Metals
Association of Czechoslovak Mining and Metallurgical Engineers (Czechoslovakia)
Association des Ingénieurs sortis de l'Ecole de Liége (Belgium)
Association Luxembourgeoise des Ingénieurs et Industriels (Luxembourg)
Australian Institute of Metals
Canadian Institute of Mining and Metallurgy
Indian Institute of Metals
Instituto del Hierro y del Acero (Spain)
Jernkontoret (Sweden)
Koninklyk Instituut van Ingenieurs (Holland)
Norsk Metallurgisk Selskap (Norway)
Société Française de Métallurgie (France)
Société Royale Belge des Ingenieurs et des Industriels (Belgium)
Verein Schweizerischer Maschinen-Industrieller (Switzerland).

Affiliated Local Societies—Associates who are members of any one of the following societies pay a reduced subscription :

Cleveland Institution of Engineers
Ebbw Vale Metallurgical Society
Leeds Metallurgical Society
Lincolnshire Iron and Steel Institute
Manchester Metallurgical Society
Newport and District Metallurgical Society
Sheffield Society of Engineers and Metallurgists
Staffordshire Iron and Steel Institute
Swansea and District Metallurgical Society.

Autumn Meeting, 1948

The Autumn Meeting of The Iron and Steel Institute was held on Wednesday and Thursday, 10th and 11th November, 1948, at the Offices of the Institute, 4, Grosvenor Gardens, London, S.W.1. The President of the Institute, Sir Andrew McCance, D.Sc., F.R.S., occupied the Chair. A full report of the proceedings at the Meeting will be printed in a later issue of the *Journal*.

Special Summer Meeting in Norway, 1949

As already announced in the August, 1948, issue of the *Journal*, the Council has received an invitation from the Norwegian Metallurgical Society (Norsk Metallurgisk Selskap) and representatives of the Norwegian metallurgical industries to hold a Special Summer Meeting in Norway in 1949. The dates of the Meeting will be from 28th May to 7th June, 1949.

Further details can be found in the August and September, 1948, issues of the *Journal*, and a circular giving full information will be issued shortly.

Andrew Carnegie Trust Fund

Grants have been made from the Andrew Carnegie Trust Fund to the following :

Mr. N. H. POLAKOWSKI : £270 to assist him in a research on the hot and cold deformation of steel and other metals, to be carried out at University College, Swansea, under the direction of Professor H. O'Neill. The award is in place of a scholarship granted in 1939 but not taken up.

Mr. W. J. WILLIAMS : £250 to assist him in a research on the individual influence of very low percentages of sulphur, manganese, silicon, phosphorus, and aluminium, on the microstructure of pure iron–carbon alloys. The research is to be carried out at the British Cast Iron Research Association.

EDUCATION

National Certificates in Metallurgy

Pass List

ORDINARY CERTIFICATE

The following candidates successfully completed the senior part-time course for the year 1947–48, and have been awarded the Ordinary National Certificate in Metallurgy ; a subject given in parenthesis indicates the award of a distinction in that subject :

Battersea Polytechnic, London—Batts, John William George (general metallurgy) ; Blewett, Richard Vernon ; Day, Joseph George ; Fricker, Dennis John (general metallurgy) ; Hall, Edward George ; Hampton, Donald Frederick George ; Mansfield, Donald Eugene ; Perkins, Raymond Frank ; Threadgold, Peter Roland ; Webster, Philip David ; Wingfield, Peter Maurice.

Birmingham Central Technical College—Bettington, Philip Josiah ; Davies, Dennis ; Hadwin, Kenneth David ; Hughes, Donald Ernest ; Lloyd, Raymond Charles (metallurgy II, chemistry II) ; Phelps, Robert Edward ; Smith, Donald Norman (metallurgy II) ; Thornton, Peter Howard ; Whitley, Gerald Henry Charles.

Chesterfield Technical College—Bonsall, Peter (inorganic chemistry) ; Burrows, Alwyne George (inorganic chemistry, physical chemistry, general metallurgy) ; Frost, George Malcolm ; Havenhand, William (inorganic chemistry) ; Peach, Raymond ; Preece, Michael Ian ; Sharman, John Colin ; Thompson, Bernal.

Coventry Technical College—Heritage, Stanley John ; Menk, Ivan Barry ; Swift, Patrick Bernard ; Timms, Ralph Graham ; Townsend, Harry ; Wood, Brian Ernest.

Cumberland Technical College, Workington—Brenan, Colin ; Hall, Alan ; Jackson, Leslie (chemistry) ; Tate, Reginald (chemistry, metallurgy, physics).

Enfield Technical College—Hickford, Jean Haidee ; Joslin, George Herbert ; Read, Allan William.

Ilkeston Technical Institute—Tomlinson, Gordon Raymond.

Newport Technical College—Cantelo, Philip John ; Meredith, Keith Edward ; Oliver, Kenneth Arthur (chemistry, general metallurgy) ; Thompson, John Alfred ; Waring, Peter.

Rotherham College of Technology—Eyre, Joseph ; Concannon, William ; Hepworth, Gordon ; Keech, Reginald ; Monks, John ; Short, Richard A. ; Stevens, Malcolm (physics) ; Timmins, Arnold ; Williams, Jack.

Scunthorpe Technical School—Bray, Bernard.

Smethwick, The Chance Technical College—Bennett, Horace ; Povey, Desmond ; Turner, Geoffrey Royston (physics) ; Westley, Kenneth Cyril ; Wragge, Gerald Patrick.

Swansea Technical College—Cumming, John Baker ; Davies, Colin James ; Evans, Leslie George ; Grey, Owen ; Lloyd, Leonard Marsden ; Richards, John Derek.

Wednesbury, County Technical College—Beddow, Alfred ; Clitheroe, John Michael ; Hares, William Charles ; Hughes, Leonard Trevor ; Johns, Raymond ; Lycett, Willis Frederick.

HIGHER CERTIFICATE

The following candidates successfully completed the advanced part-time course for the year 1947–48, and have been awarded the Higher National Certificate in Metallurgy :

Battersea Polytechnic, London—Dunthorne, Hector Barrett ; Hull, William Griffin.

Birmingham Central Technical College—Hearnshaw, Gwendoline Frances ; Rogers, Colin Francis.

Chesterfield Technical College—Cumberland, John ; Fearn, Eric Bernard Nelson ; Geary, Roy ; Pyrah, Alan ; Slater, John Linder ; Turner, Luther.

Rugby College of Technology—Ashton, Geoffrey (distinction in inorganic and physical chemistry).

Rutherford College of Technology—Allon, Frederick R. H. ; Brown, James Albert ; Chennels, William ; Millican, Frederick Douglas.

Wednesbury, County Technical College—Boys, Sidney Joseph Henry ; Doo, Betty ; Winfield, Gerald.

Wolverhampton and Staffordshire Technical College—Cartwright, Harry ; Hipwell, Robert Charles ; Walsh, Marjorie Elaine ; Wilkes, Thomas Orlando George.

Prizes

Prizes to be taken in books have been awarded to the following candidates in respect of the Final Examinations for Ordinary and Higher National Certificates in Metallurgy for the year 1947–48 :

Battersea Polytechnic, London—Betts, John William George (two guineas) ; Fricker, Dennis John (one guinea).

Birmingham Central Technical College—Lloyd, Raymond Charles (three guineas) ; Smith, Donald Norman (two guineas).

Chesterfield Technical College—Bonsall, Peter (one guinea) ; Burrows, Alwyne George (five guineas) ; Havenhand, William (one guinea).

Cumberland Technical College, Workington—Jackson, Leslie (one guinea) ; Tate, Reginald (five guineas).

Newport Technical College—Oliver, Kenneth Arthur (four guineas).

Rotherham College of Technology—Stevens, Malcolm (two guineas).

Smethwick, The Chance Technical College—Turner, Geoffrey Royston (one guinea).

Rugby College of Technology—Ashton, Geoffrey (two guineas).

Swansea Technical College—Cumming, John Baker (one guinea) ; Evans, Leslie George (one guinea).

Wednesbury, County Technical College—Lycett, Willis Frederick (one guinea).

Wolverhampton and Staffordshire Technical College—Cartwright, Harry (one guinea).

NEWS OF MEMBERS

► Mr. NORMAN U. BREMNER, of Messrs. Guest, Keen and Baldwins Iron and Steel Co., Ltd., has been transferred to their works at Briton Ferry, Glam.

► Mr. D. R. G. DAVIES has resigned his position as chief metallurgist to the Panteg Branch of Messrs. Richard Thomas and Baldwins, Ltd., and is taking up his studies under a Mond Nickel Fellowship in London and America.

► Sir JOHN DUNCANSON has resigned his position of Commercial and Technical Director of the British Iron and Steel Federation. He will be succeeded by Mr. E. W. SENIOR.

► Mr. ELWYN EVANS has been appointed as a scientific officer at the Metallurgy Division of the National Physical Laboratory, Teddington, Middlesex.

► Dr. K. L. FETTERS has, with Mr. J. L. Manthe, been awarded the American Iron and Steel Institute Medal for their paper on "*The Mineralogy of Basic Open-Hearth Slag*," presented to the American Iron and Steel Institute in 1947.

▶ Dr. M. C. FETZER has left the Carpenter Steel Company, Reading, Pennsylvania, and has taken up a position at the Latrobe Electric Steel Company, Latrobe, Pennsylvania, U.S.A.

▶ Mr. NATHANIEL C. FICK has been appointed Deputy Scientific Director of the Committee on Basic Physical Sciences of the Research and Development Board, in Washington, U.S.A.

▶ Mr. R. W. FIRTH, having left Durham University with the degree of B.Sc. in metallurgy, has been appointed foundry metallurgist with the David Brown Foundries Co., Ltd., Penistone.

▶ Mr. J. L. HARRISON has left Messrs. Catton and Co., Ltd., Leeds, to take up an appointment with the Low Moor Alloy Steelworks, Ltd., at Low Moor, Bradford.

▶ Lt.-Col. J. P. HUNT has been elected Master Cutler of Sheffield for the ensuing year.

▶ Mr. GLANVILLE JONES has left The United Steel Companies, Ltd., Stocksbridge, near Sheffield, to become chief metallurgist at the Panteg Works of Messrs. Richard Thomas and Baldwins, Ltd., Griffithstown, near Pontypool.

▶ Mr. G. L. JONES has left the Ministry of Supply to join the Development Division of Aluminium Laboratories, Ltd., Banbury, Oxon.

▶ Dr. JOHN R. LOW, jun., previously at the Division of Metallurgy, School of Mineral Industries, Pennsylvania State College, has joined the General Electric Company at their Knolls Atomic Power Laboratory, 425, Peek Street, Schenectady, New York.

▶ Sir ANDREW MCCANCE, F.R.S., President of The Iron and Steel Institute, has agreed to be a Vice-President of the Fourth Empire Mining and Metallurgical Congress, which is to be held in Great Britain from 9th to 23rd July, 1949.

▶ Mr. J. MACKENZIE has recently received the degree of B.Sc. and is joining the metallurgical staff of the Union Corporation Group of Gold Mines in South Africa.

▶ Mr. E. MORGAN has joined the Research Department of the Metal Box Co., Ltd., Neath, Glam.

▶ Mr. A. W. READ-PRYCE is now works manager of Metalex Pty., Ltd., Melbourne, Australia.

▶ Mr. EDGAR G. REES is Chairman and Managing Director of a new private limited company under the name of Rees Industries, Ltd., of Llanelly.

▶ Mr. F. SHEPHERD has succeeded Mr. CHRIS MOODY as President of the Cleveland Institution of Engineers.

▶ Col. A. STEIN has been appointed to the Scottish Council of the Federation of British Industries.

▶ Mr. F. M. THOMAS, having graduated from Swansea University with second-class honours in metallurgy, has joined the Appleby-Frodingham Steel Company.

▶ Mr. G. R. WALSHAW, J.P., has retired from the Appleby-Frodingham Steel Company, Scunthorpe.

▶ MR. A. H. WHITEHOUSE has left the British Iron and Steel Research Association, and has joined the Skefko Ball Bearing Co., Ltd., as a technical representative, in their Birmingham Office.

▶ Mr. C. A. E. WILKINS is taking up an appointment as metallurgist at the Abadan works of the Anglo-Iranian Oil Co., Ltd.

Obituary

The Council regret to record the deaths of the following :

Sir PETER BOSWELL BROWN, Honorary Vice-President, on 12th October, 1948, aged 82.

Mr. WILLIAM HUTTON CATHCART, metallurgical manager at Messrs. Lobnitz and Co., Ltd., Renfrew, from 1919 until 1944, on 16th September, 1948.

Sir W. PETER RYLANDS, Bt., J.P., Past-President, on 23rd October, 1948, the eve of his 80th birthday.

CONTRIBUTORS TO THE JOURNAL

F. Wormwell, M.Sc., Ph.D.—Principal Scientific Officer, Chemical Research Laboratory of the Department of Scientific and Industrial Research, Teddington. Dr. Wormwell was born at Nelson, Lancashire, in 1906, and was educated at Nelson Secondary School and Manchester University, where he graduated in Chemistry (first-class honours) in 1926. He received the M.Sc. degree in 1927 for a thesis on electro-kinetic phenomena and after a further year's research was appointed to the scientific staff of the Chemical Research Laboratory. Since then he has been engaged in investigations of the corrosion of metals, originally under the direction of the late Dr. G. D. Bengough, F.R.S., and latterly under Dr. W. H. J. Vernon, O.B.E. He received the Ph.D. degree (external) of London University, in 1933, for a thesis on the quantitative study of the corrosion of immersed metals.

H. C. K. Ison—Experimental Officer in the Corrosion Section of the Chemical Research Laboratory. Born in 1911, Mr. Ison was educated at Bablake, Coventry, and at Birmingham Central Technical College. He was awarded the First Prize and Silver Medal for iron and steel manufacture (1933) and for non-ferrous metallurgy (1934) of the City and Guilds of London Institute final examinations. He was also awarded the Thomas Turner Bronze Medal for Metallurgy in 1934. After several years' industrial experience Mr. Ison went to the Chemical Research Laboratory in 1935 where he is engaged in research under Dr. W. H. J. Vernon, O.B.E.

T. J. Nurse—Senior Experimental Officer at the Chemical Research Laboratory of the Department of Scientific and Industrial Research, Teddington. Mr. Nurse was educated at Llanelly County School and at Swansea Technical College. He served for five years on the laboratory staff of Messrs. Richard Thomas and Co., Ltd., and from 1927 to 1930 he was employed with Messrs. G. Rudd, Thompson and Partners, Ltd., public analysts, Newport, Mon. He was appointed to the Chemical Research Laboratory in 1930, since when he has been engaged, in association with Dr. F. Wormwell, on investigations of the corrosion of metals.

R. St. J. Preston, M.Sc., F.R.I.C.—Principal scientific officer in the Chemical Research Laboratory, Department of Scientific and Industrial Research. Born in 1897 and educated at Liverpool Collegiate (High) School, Mr. Preston gained a scholarship to Liverpool University where, after active service in the 1914–18 war, he graduated in the honours chemistry school, receiving the Leblanc Medal, and later obtained the M.Sc. degree.

After gaining industrial experience with the British Aluminium Company, Mr. Preston joined the Ministry of Transport Experimental Station where he was in charge of the testing of road materials. During the

H. C. K. Ison

R. St. J. Preston

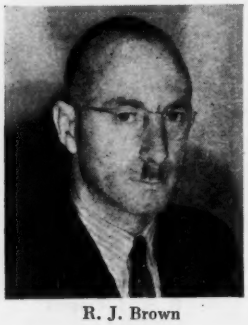
recent war he assisted the Ministry of Supply as production manager in their Chemical Defence Research Establishment and as plant manager in their factory at Runcorn.

For the past four years Mr. Preston has been associated with Dr. W. H. J. Vernon at the Chemical Research Laboratory where he has been engaged on various corrosion problems.

R. J. Brown, F.I.M., A.M.I.Mech.E.—Chief chemist and metallurgist, Nuffield Central Research Laboratories and Morris Motors, Ltd., Engines Branch. Born in 1910, Mr. Brown was educated at Coventry Junior Technical School and at Birmingham Central Technical College. He was awarded the Silver Medal of the City and Guilds Institute, and the Bronze Medal of the Birmingham Metallurgical Society. He gained practical experience in the laboratories of several engineering works and joined Morris Motors in 1929, where he became senior assistant metallurgist of the Engines Branch in 1933, and chief chemist and metallurgist in 1935. In 1945 he was also appointed in charge of the newly formed Nuffield Central Research Laboratories. From 1935 until 1940 Mr. Brown served as a part-time lecturer in metallurgy at Birmingham Central Technical College and at Coventry Technical College.

F. D. Richardson, B.Sc., Ph.D.—Head of the Chemistry Department, British Iron and Steel Research Association. Dr. Richardson is a graduate of University College, London, where he carried out research on the physical chemistry of the oxides of chlorine. After a short period of research for the Admiralty, under the auspices of the Department of Scientific and Industrial Research, he was appointed Commonwealth Fellow at Princeton University, where he worked on the photo-chemistry of reactions involving solids. Serving in the Royal Navy, in a scientific capacity, Dr. Richardson was associated with the development of new weapons and equipment, and for three years was Deputy Director of Miscellaneous Weapon Development. He joined B.I.S.R.A. in 1946 to form the Chemistry Department, which is concerned with the fundamental chemistry of iron and steel processes, refractories, and corrosion.

J. H. E. Jeffes, B.Sc.—In charge of the physical chemistry section of the Chemistry Department of the British Iron and Steel Research Association. Mr. Jeffes was a scholar of New College, Oxford, where he specialized in thermodynamics and carried out research work on low-temperature specific heats and on hydrogen bond formation in organic solvents. During the recent war he served in the Royal Navy and was concerned with the development of special weapons both in this country and in India. He joined B.I.S.R.A. in 1946 and has since been engaged in fundamental research and in the establishment of the chemistry laboratory at Battersea.



R. J. Brown

F. D. Richardson

IRON AND STEEL ENGINEERS GROUP

Joint Meeting at Sheffield

A Joint Meeting of the Iron and Steel Engineers Group and the Institution of Production Engineers, Sheffield Section, will be held at the Royal Victoria Station Hotel, Sheffield, on 12th January, 1949, at 6.30 P.M. Mr. W. F. Cartwright, Chairman of the Iron and Steel Engineers Group, will present a paper entitled "*The Steel Company of Wales—Development at Port Talbot.*" Mr. G. R. Pryor, President of the Sheffield Section of the Institution of Production Engineers, will be in the Chair.

AFFILIATED LOCAL SOCIETIES

The Lists of Officers for the session 1948–49 are as follows:

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NEWS OF SCIENCE AND INDUSTRY

Fourth Empire Mining and Metallurgical Congress

The Fourth Empire Mining and Metallurgical Congress is to be held in Great Britain from 9th to 23rd July, 1949. The chief object of the Congress is to afford opportunities for scientists, engineers, and others concerned with the mining and metallurgical industries, to meet and discuss technical progress and problems, including development of mineral resources of the Commonwealth.

The programme will be divided into three parts: (1) Inaugural meeting and other official functions in London, (2) technical sessions in Oxford, and (3) excursions based mainly on Universities in Great Britain.

Technical Sessions and Papers—The papers to be discussed at the various sessions will be concerned chiefly with subjects of general interest. It is expected that the subjects will include the mineral resources of the Commonwealth, coal-mining practice, ferrous and non-ferrous metallurgy and mineral dressing, modern methods of mineral exploration, petroleum technology, and the effects of heat and humidity on workers in deep mines and in metallurgical works.

Membership—Anyone interested in the subjects to be discussed, irrespective of nationality, may apply for membership of the Congress. Special arrangements are being made for ladies accompanying members of the Congress. The membership fee will be £2. A member's wife or other near relative will not be required to pay an additional membership fee. Application for membership should be made *at the earliest possible date* to the General Secretaries, Fourth Empire Mining and Metallurgical Congress, 436, Salisbury House, Finsbury Circus, London, E.C.2, from whom further details may be obtained. More detailed arrangements for the programme will be published in a later issue of the *Journal*.

"Design at Work" Exhibition

The first exhibition of the work of Royal Designers for Industry was opened by H.R.H. the Duchess of Kent at the Royal Academy of Arts, Burlington House, London, W.1, on 26th October, 1948. The exhibition, which is sponsored by the Royal Society of Arts and the Council of Industrial Design, will be open to the public until 28th November, 1948; it demonstrates the contribution of the designer to the manufacture of products that work well, look well, last well, and sell well.

It is also intended that the exhibition shall be a useful forerunner to the centenary in 1951 of the Great Exhibition of 1851 by stimulating now the production of British goods of outstanding design in time for showing to the world during the 1951 Festival of Britain.

Mond Nickel Fellowships

The Mond Nickel Fellowships Committee has pleasure in announcing the following three awards for 1948:

Mr. S. G. CAMPBELL (Plessey Company, Limited): To study the various stages of the organization from research to large-scale production of specialized metallurgical industries in the United States of America and in Canada.

Mr. S. J. GARVIN (Murex, Limited): To study the application of sponsored research, and the administrative methods employed, in the powder metallurgical industries in the United States of America.

Mr. A. I. NUSSBAUM (Thos. Firth and John Brown, Limited) to study the application of rolling-mill research, mill plant development, and the theory of rolling, to the manufacture of rolled steel products.

The Mond Nickel Fellowships Committee will, at a later date, invite applications for awards for 1949. Full particulars of the Fellowships can be obtained from the Secretary, Mond Nickel Fellowships Committee, 4, Grosvenor Gardens, London, S.W.1.

Research Fellowship in Extraction Metallurgy

The establishment is announced of a Research Fellowship in extraction metallurgy, funds for which have been provided by the Nuffield Foundation. It will be awarded in consultation with the Institution of Mining and Metallurgy and the Royal School of Mines, and will be tenable at the Royal School of Mines for a period of five years. The funds are sufficient to provide a small specialist staff and the necessary equipment, in addition to adequate remuneration for the Fellow. Applicants should have had experience in the initiation and development of research.

Applications, giving details of qualifications and experience and the names of three referees, together with suggestions as to the lines of research it is proposed to follow, should reach the Secretary, Institution of Mining and Metallurgy, Salisbury House, London, E.C.2, *not later than 30th November*, 1948.

DIARY

24th Nov.—INSTITUTE OF PHYSICS (South Wales Branch)—"*Recent Theories of Creep in Metals*," by N. F. Mott—University College, Cardiff, 4.15 P.M.

24th Nov.—IRON AND STEEL ENGINEERS GROUP—Eighth Meeting—4, Grosvenor Gardens, London, S.W.1, 10.30 A.M.

25th Nov.—MIDLAND METALLURGICAL SOCIETIES—"*High-Temperature Measurements*," by T. Land—James Watt Memorial Institute, Great Charles Street, Birmingham, 6.30 P.M.

30th Nov.—INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND—"*Recent Research in Caustic Cracking in Boilers*," by C. D. Weir—39, Elmbank Crescent, Glasgow, 6.30 P.M.

1st Dec.—LIVERPOOL METALLURGICAL SOCIETY (Joint Meeting with the Liverpool Engineering Society)—"*The Co-Relation of Metallurgical Research and Development with Engineering Requirements*," by L. W. Johnson—9, The Temple, 24, Dale Street, Liverpool—7.0 P.M.

2nd Dec.—INSTITUTE OF WELDING (Sheffield and District Branch)—"*The Welding of Stainless Steel*," by J. A. McWilliam—Royal Victoria Station Hotel, Sheffield, 6.30 P.M.

2nd Dec.—LEEDS METALLURGICAL SOCIETY—"*Recent Developments in Photo-Elasticity*," by Dr. Ward—Chemistry Department, the University, Leeds, 7.0 P.M.

2nd Dec.—MIDLAND METALLURGICAL SOCIETIES—"*The Treatment and Properties of Springs*," by B. Coates—James Watt Memorial Institute, Great Charles Street, Birmingham, 6.30 P.M.

2nd Dec.—NEWPORT AND DISTRICT METALLURGICAL SOCIETY—Film on "*Atomic Physics*"—Whitehead Institute, Cardiff Road, Newport, Mon., 7.0 P.M.

6th Dec.—CLEVELAND INSTITUTION OF ENGINEERS—"*Blast-Furnace Relining*," by G. D. Elliott and A. Bridge—Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough, 6.30 P.M.

7th Dec.—SHEFFIELD METALLURGICAL ASSOCIATION—"*Some Selected Problems in the Creep of Metals*," by W. E. Bardgett—198, West Street, Sheffield, 7.0 P.M.

9th Dec.—INSTITUTE OF METALS (London Local Section) (Joint Meeting with the London Branch of the Institute of British Foundrymen)—"*The Solidification of Metals with Special Reference to Continuous-Casting Processes*," by E. Scheuer—4, Grosvenor Gardens, London, S.W.1, 7.0 P.M.

9th Dec.—INSTITUTE OF WELDING (South London Branch)—"*Some Aspects of the Metallurgical Side of Welding*," by H. F. Tremlett—85–88, The Minories, London, E.C.3, 6.30 P.M.

11th Dec.—SWANSEA AND DISTRICT METALLURGICAL SOCIETY—"*The Assessment of Hot-Dipped Protective Coatings*," by M. L. Hughes—Swansea, 6.30 P.M.

13th Dec.—INSTITUTE OF BRITISH FOUNDRYMEN (Sheffield Branch)—"*Nodular Cast Irons—Their Production and Properties*," by H. Morrogh and J. W. Grant—Royal Victoria Station Hotel, Sheffield, 7.30 P.M.

14th Dec.—EBBW VALE METALLURGICAL SOCIETY (Joint meeting with the Iron and Steel Engineers Group)—"*Maintenance and Materials*," by F. E. Probyn—Lesser Workmen's Hall, Ebbw Vale, 7.0 P.M.

14th Dec.—SHEFFIELD METALLURGICAL ASSOCIATION—"*Forged Steel Rolls—Their Application and Manufacture*," by A. H. Waine—198, West Street, Sheffield, 7.0 P.M.

17th Dec.—WEST OF SCOTLAND IRON AND STEEL INSTITUTE—"*The Application of Slag Control to the Manufacture of Tube Steel*," by J. Monaghan, and "*Factors Affecting the Quality of Pig Iron for Steel Making*," by R. P. Towndrow—39, Elmbank Crescent, Glasgow, 6.45 P.M.

20th Dec.—SHEFFIELD SOCIETY OF ENGINEERS AND METALLURGISTS (Joint meeting with the Iron and Steel Engineers Group)—"*The Maintenance of Electrical Machinery in Iron and Steel Works*," by G. S. Martin and M. Y. Harvey—Royal Victoria Station Hotel, Sheffield, 6.15 P.M.

TRANSLATION SERVICE

(The previous announcement was made in the October, 1948, issue of the *Journal*, p. 216)

TRANSLATIONS AVAILABLE

No. 359 (German). B. MATUSCHKA: "The Heat Equilibrium Between Ingot and Ingot-Mould Wall." (*Archiv für das Eisenhüttenwesen*, 1929, vol. 2, June, pp. 405–411.)

No. 360 (German). H. SCHUMACHER: "Relationship Between Blast-Furnace Burden and Fuel Economy in Iron and Steel Works." (*Stahl und Eisen*, 1947, vol. 66–67, Nov. 6, pp. 375–379.)

No. 361 (German). (*a*) JOHANNA HUNGER and R. SEELIGER: "The Presentation of Relief in the Ultra-Microscope by Means of Pressed and Double-Layer Replicas." (*Metallforschung*, 1947, vol. 2, Mar., pp. 65–69.)

(*b*) H. MAHL: "Electron Micrographs of Steel Fractures." (*Metallforschung*, 1947, vol. 2, June, pp. 186–188.)

No. 362 (Polish). L. WUSATOWSKI: "Graphical Methods for Calibrating Mill Rolls." (*Hutnik*, 1947, vol. 14, Apr., pp. 206–219.)

No. 363 (Swedish). G. WALLQUIST: "Graphical Roll Calibration." (*Jernkontorets Annaler*, 1948, vol. 132, No. 2, pp. 27–41.)

PAPERS ACCEPTED FOR TRANSLATION SINCE THE LAST ANNOUNCEMENT

(German). P. KLINGER and W. KOCH: "Progress in the Isolation of Inclusions and Structural Constituents in Alloy and Unalloyed Steels." (*Stahl und Eisen*, 1948, vol. 68, Sept. 9, pp. 321–333.)

(German). (*a*) G. NAESER: "The Development of a Process for the Manufacture of High-Quality Basic Bessemer Steel (MA Steel)." (*Verein Deutscher Eisenhüttenleute, Düsseldorf, Confidential Report No.* 67 (1944).)

(*b*) W. BADING: "Production of Hot-Blown, Low-Nitrogen Steel." (*Verein Deutscher Eisenhüttenleute, Düsseldorf, Confidential Report No.* 67 (1944).)

(German). H. REINFELD: "The Production of Ferro-Manganese from Low-Grade Ores." (*Stahl und Eisen*, 1948, vol. 68, Jan. 29, pp. 39–43.)

(Dutch). W. SOETE: "The Determination of Internal Stresses." (*Metalen*, 1948, vol. 2, July, pp. 231–245.)

(Russian). I. YA. TARNOVSKIY: "The Calculation of Mean Reduction in Pass Rolling." (*Stal*, 1948, No. 3, pp. 232–240.)

TRANSLATIONS PREPARED AT MEMBERS' REQUEST.—Members requiring translations of foreign papers are invited to communicate with the Secretary, who will ascertain whether the translations can be prepared for inclusion in the Series.

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

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FUEL—PREPARATION, PROPERTIES, AND USES

Determination of the Fusibility of Fuel Ash in Reducing Atmospheres. E. Rousseau. (Chimie et Industrie, 1948, vol. 60, Aug., pp. 124–136). A method of computing curves for the fusibility of ash in the presence of oxidizing or reducing gases is described. The data for these curves must be determined in the presence of such gases, in order to obtain results which are applicable to conditions encountered in industrial practice. After discussing the combustion of coal the author describes the apparatus and method used for his tests. The results obtained with oxidizing and reducing atmospheres are compared.—R. F. F.

The Drying of Coal. W. J. Kramers and J. H. McKee. (Monthly Bulletin of the British Coal Utilisation Research Association, 1948, vol. 12, May, pp. 157–175). The increased use of water for dust suppression and coal preparation has thrown more emphasis on the problem of coal drying. The work of various investigators who have studied this problem, and the results obtained with the various types of driers at present in use, are reviewed. A bibliography of 46 references is appended.—R. F. F.

Coke Manufacture at Michel Colliery. T. H. Wilson and W. R. Prentice. (Transactions of the Canadian Institute of Mining and Metallurgy, 1947, vol. 50, pp. 567–576). A description is given of the battery of 20 Curran-Knowles coke ovens in the Michel Valley, Vancouver. These ovens are horizontal chambers 32 ft 6 in long × 8 ft 3 in wide × 4 ft high at the centre. Operating data are presented.—R. A. R.

The Preparation of Coke for Blast Furnaces. L. M. Tsylev and N. P. Banny. (Izvestia Akademia Nauk, S.S.S.R., 1946, No. 1, pp. 115–120).

REFRACTORY MATERIALS

The Effects of Firing Silico-Aluminous Refractories. V. Bodin. (20e Congrés de Chimie Industrielle, Sept. 22–28, 1946 : Chimie et Industrie, 1948, vol. 59, June, pp. 542–547). Tests were carried out on five commercial refractory products, to study the effect of firing on the properties of the bricks. The bricks were tested after industrial firing and in the unfired state. The bricks were subjected to gradual increase of heat and one of each type was kept at temperatures of 1400°, 1500°, 1600°, and 1700° C for 6 hr and then slowly cooled. The effect of this treatment on shock resistance, refractoriness-under-load, structure, and characteristics of the bricks is discussed. On the basis of these results firing at high temperatures is suggested.—R. F. F.

Manufacture of High-Alumina Refractories for Tube-Welding Furnaces. L. E. Krushel. (Ogneupory, 1947, vol. 12, p. 80 : British Ceramic Abstracts, 1948, Mar.–Apr., p. 96A). An aluminous grog is prepared by grinding together equal parts of fireclay and commercial alumina (or an equivalent amount of hydrated alumina), dry-pressing the mixture into briquettes and firing at 1480°–1500° C. A mixture of this grog (maximum grain size 7 mm., not less than 20% fines) with 15% of fireclay is dry-pressed or rammed and fired at 1500°–1550° C. The products compare favourably with imported blocks containing calcined kyanite. A suggested plant layout for the process is appended.

High Quality Blast-Furnace Bricks as Produced in the Semiluk Works. S. V. Glebov, A. K. Karklit, I. A. Savkevich, and R. S. Milshenko. (Ogneupory, 1947, vol. 12, p. 152 : British Ceramic Abstracts, May–June, pp. 163A–164A). Laboratory tests showed that fireclay bricks of Latnen clay with an addition of 10% alumina would not only reach the standard required by the Soviet Government Specifications, but would also surpass in quality a typical American blast-furnace brick of similar type. A description is given of the production of these high-quality bricks in the Latnen Works. The kiln-charging system is shown, and the proportion of firsts, seconds, and rejects is analysed. The quality of the product is compared with that produced in the Chassov-Yar factory and with a typical American product.

Refractories in the Iron and Steel Industry. H. Greenbaum. (Clay Prod. Journal Australia, 1947, vol. 14, No. 11, p. 3 : British Ceramic Abstracts, 1948, May–June, p. 193A). A brief outline is given of the requirements and the six principal types of refractory bricks, also of their importance to various industries. Their improvement makes for increased production, reduction in maintenance costs, and effects appreciable saving in fuel consumption.

Foundry Refractories. Their Properties and Application. C. A. Brashares. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 759–763). *See* Journ. I. and S.I., 1947, vol. 156, May, p. 131.

Methods of Determining Additional Shrinkage and Additional Growth of Refractories. E. K. Keler. (Ogneupory, 1946, vol. 11, No. 7–8, pp. 23–27 : American Ceramic Abstracts, 1948, June 1, p. 130).

Silica Brick from Osokarov Quartzite Deposits. V. A. Bron: and T. S. Ignatova. (Ogneupory, 1947, vol. 12, pp. 27–34 , Chemical Abstracts, 1948, vol. 42, June 20, col. 4319).

Methods of Improving the Physicochemical Characteristics of Blast-Furnace Brick. S. A. Zhikharevich. (Ogneupory

1946, vol. 11, No. 1, pp. 25–38 : American Ceramic Abstracts, 1948, May 1, p. 103).

Forsterite Refractories from Serpentine. V. M. Tsynkina. (Ogneupory, 1946, vol. 11, No. 6, pp. 25–35 : American Ceramic Abstracts, 1948, May 1, p. 101).

Heat Resistance of Refractories Made from Magnesite and Chromite. A. P. Panarin. (Ogneupory, 1946, vol. 11, No. 6, pp. 14–22 : American Ceramic Abstracts, 1948, May 1, p. 102).

Consumption of Basic Refractories in Open-Hearth Furnaces. M. A. Luri. (Ogneupory, 1947, vol. 12, p. 261 : British Ceramic Abstracts, 1948, May–June, p. 163A). The specific consumption of basic refractories per ton of open-hearth steel in each part of 59 furnaces is studied and the mean total specific consumption calculated for four types of furnace. The relationships between specific consumption and number of melts per furnace campaign is also examined and lines of regression are drawn to establish a linear relationship between the two values.

Use of Fire-Brick in Open-Hearth Furnace Back Walls. M. Y. Kuzelov and A. A. Skvortsov. (Ogneupory, 1947, vol. 12, p. 174 : British Ceramic Abstracts, 1948, May–June, p. 163A). In order to reduce consumption of magnesite and chrome-magnesite refractories, back walls of open-hearth furnaces in a Russian plant are lined with a layer of magnesite bricks superimposed on a layer of firebricks. The best proportions are found to be 230 mm (9 in) thickness for the firebrick layer and 460 mm (18 in) for the magnesite.

Chrome-Dolomite High Refractory Concrete and Brick. P. P. Budnikov. (Comptes Rendus (Doklady) de l'Académie des Sciences de l'U.R.S.S., 1946, vol. 51, p. 615 : British Ceramic Abstracts, 1948, May–June, p. 193A). Results of tests on an unfired chrome-dolomite refractory showed that it may replace magnesite and chrome-magnesite bricks in steel furnaces. A chrome-dolomite refractory in the form of a metal-cased tube was tested in the end wall of a 40-ton open-hearth furnace operating on oil. At the point in question silica and other refractories withstood from 40 to 50 melts, whereas the chrome-dolomite refractory withstood 370 melts. In the back wall of an open-hearth furnace, disintegration of chrome-dolomite bricks and magnesite bricks was identical. It is concluded that the use of unfired chrome-dolomite bricks effects big savings in fuel and cuts down the consumption of magnesite.

Production of Steel-Casting Stoppers by the Refractories Section of the Stalin Metallurgical Works at Kuznetsk. E. A. Kogan. (Ogneupory, 1946, vol. 11, No. 9–10, pp. 3–10 : American Ceramic Abstracts, 1948, June 1, p. 131). Up to 1942, the open-hearth division of the Stalin Metallurgical Works at Kuznetsk used grog-graphite steel-casting stoppers with unsatisfactory results. The quality of the stoppers was somewhat improved by reducing the fine grog fraction ($< 0{\cdot}5$ mm) to about 45–50%. The lack of high-quality clay and graphite during the war made it necessary to use a charge consisting of 55% andalusite, 10% grog, and 35% clay. These stoppers proved satisfactory; after casting 180 to 200 tons of steel in 80 to 100 min, the shape of the stoppers remained practically unchanged, the surface was coated with slag 1·5 to 2·0 mm thick, and the fracture was smooth and porcelain-like in appearance. As the andalusite became adulterated with quartz and mica, however, the quality of the stoppers dropped sharply. Finally, the use of andalusite containing less than 45% alumina was discontinued. Since 1944 stoppers have been made from a charge of 35% Chasov-Yar clay and 65% grog. The stoppers served under severe conditions in 180 to 195-ton ladles and remained for 100 to 125 min in liquid metal. After service they were somewhat flattened in a vertical direction, the surface was covered with slag 1 to 1·5 mm thick, fracture showed a dense mass of white colour with porcelain-like grains of grog, and large pores and cavities were not visible.

Soluble Silicates and the Refractories Industry. H. L. Bolton. (American Ceramic Society Bulletin, 1948, vol. 27, June 15, pp. 229–234). The literature on many applications of solutions containing silicates in the refractory industry is reviewed. The applications cover cements, mortars, plastic refractories, and certain special purposes such as increasing the resistance of insulating bricks to slag attack. There are 42 references.—R. A. R.

Ceramic Linings for Jet Engines. L. A. Shaw. (Ceramic Industry, 1948, vol. 50, Jan., p. 47 : [Abstract] Monthly Bulletin of the British Coal Utilisation Research Association, 1948, vol. 12, May, p. 188). This is a note on a proposal to investigate a process of " vapour plating " of metals on to refractory linings.

Rammed Refractories for Electric Furnaces. R. H. Zoller. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 456–459). *See* Journ. I. and S.I., 1947, vol. 156, May, p. 131.

Suggested Cupola Refractory Standardization. R. P. Stevens. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 378–379). The standardizing of the sizes and shapes of refractories for cupolas is recommended.—R. A. R.

BLAST-FURNACE PRACTICE AND THE PRODUCTION OF PIG IRON

Combustion and Flow of Gases in Cowper Stoves. J. Szczeniowski. (Chaleur et Industrie, 1948, vol. 29, Aug., pp. 179–187). Theoretical and practical examples are given of problems arising out of the combustion and flow of gases in Cowper stoves.—J. C. R.

Calculation of a Charge for the Zapla Blast-Furnace with the Mathesius Triangular Diagram. F. Rochna. (Revista Minera, Geologia y Mineralogia, Sociedad Argentina de Mineria y Geologia, 1945, vol. 16, pp. 64–80).

Notes on Modern Blast Furnace Technique. M. Brun and M. Legendre. (Métallurgie, 1948, vol. 80, May, pp. 9, 11–13; June, pp. 9–11, 13; July, pp. 7–9; Aug., pp. 7–8). Continuing this series of articles (*see* Journ. I. and S.I., 1948, vol. 159, July, p. 324) the authors first deal with the capacity of modern blast-furnaces and explain why increased capacity is obtained by increasing the diameter rather than the height. The profile, hearth, bosh, and single- and double-closing types of blast-furnace top are described and their function explained. Part two gives an account of the distribution of the burden when the blast-furnace is charged and the factors that have to be taken into consideration. Part three deals with refractory bricks used to line the blast-furnace, the properties of silico-alumina bricks, the respective advantages and disadvantages of large and small bricks, and the use of carbon blocks for the blast-furnace hearth. Part four deals with water-cooling systems.

The Possibility of Desulphurization of Cast Iron with Manganese Derived from Blast-Furnace Slag. A. Piechota. (Przeglad Chemiczny, 1947, vol. 5, pp. 143–144 : Chemical Abstracts, 1948, vol. 42, Aug. 10, col. 5390). Sulphur present in blast-furnace slag combines with manganese provided the manganese content is large enough to bind the whole amount of sulphur. In the presence of a small amount of manganese, sulphur combines with calcium and aluminium. The acidity or alkalinity of the slag has no effect on the process.

PRODUCTION OF STEEL

Manufacture of Low-Nitrogen, Low-Phosphorus Steel in the Basic Converter. (Iron and Coal Trades Review, 1948, vol. 157, Aug. 20, pp. 407–408). Various methods for producing H.P.N. (low nitrogen, low phosphorus) steel are described, including that adopted at Dortmund Hörde Hüttenverein, the " double-blowing " process, and the Perrin process. J. C. R.

Removal of Phosphorus in the Manufacture of Basic Open-Hearth Steel. K. G. Lewis. (Iron and Coal Trades Review, 1948, vol. 157, Aug. 13, pp. 345–350). The various stages at which removal of phosphorus in the basic open-hearth process can be effected are discussed, together with theories underlying the mechanism of phosphorus removal during working. In particular, reference is made to the elimination of phosphorus by slag removal, removal of phosphorus during the working period, prevention of phosphorus reversal during deoxidation, the reversal of phosphorus during teeming, and the function of manganese oxide and ferric oxide in controlling phosphorus.—J. C. R.

The Concept of " Normal Charge " for Steelworks Furnaces. L. Bruno. (Metallurgia Italiana, 1947, vol. 39, Jan.–Feb., pp. 24–29 : [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 7, p. 1281).

The "normal charge" consists of iron, scrap, spiegeleisen, and lime, and it must enable the desired composition to be obtained without the addition of oxidizing or recarburizing agents. This "charge" serves as the basis for calculations for controlling furnace operation and obtaining minimum prime costs. Practical examples of the calculations involved are given.

The Use of Oxygen in Steelmaking. G. V. Slottman. (Engineers' Digest (N.Y.), 1948, vol. 5, July, pp. 223, 268). The history of the use of oxygen in steelmaking is outlined with particular reference to recent developments in its use in the open-hearth furnace.—J. C. R.

Density and Viscosity of Slag and Metal Bath in the System Iron–Tungsten–Chromium. L. Losana. (Metallurgia Italiana, 1947, vol. 39, Jan.–Feb., pp. 5–11: Chemical Abstracts, 1948, vol. 42, Apr. 20, col. 2564). The densities of chromium, tungsten, and chromium–tungsten steels have been measured in the liquid state in the temperature range 1600–1700°. Small amounts of chromium affect the density only slightly. Tungsten, however, affects the density more markedly. Viscosity of iron–tungsten alloys was determined in the same temperature range, as well as the density and viscosity of the ternary alloys iron–chromium–tungsten, up to 25% tungsten and 10% chromium. Densities of slags of varying CaO/SiO_2 ratios with varying amounts of WO_3 and Cr_2O_3 were also determined. These values were used for calculating the rise of various slags in typical metal baths.

Comments on Furnace Practice in Western Europe. W. B. Wallis. (Journal of the Electrochemical Society, 1948, vol. 93, Mar., pp. 46N–50N). The author compares electric-furnace practice in Europe, especially Sweden and Germany, with United States methods. He discusses the use of rotating hearths, which have not proved wholly satisfactory, charging methods, refractories, controls in which in some cases he finds European methods superior, and concludes that, where waterpower developments provide cheap and plentiful electric power, European production of electric-furnace steel may within the next ten years reach and exceed pre-war percentages.—J. P. S.

Some Electric Arc Furnace Problems. S. I. Telnyj. (Elektrichestvo (U.S.S.R.), 1947, No. 2, pp. 48–53: [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 7, p. 1194).

What is Refined Steel? O. Pattermann. (Betrieb und Fertigung, 1948, vol. 2, Apr., pp. 73–78). Refined steel (Edelstahl) is discussed from two points of view, namely, as a very expensive steel and as alloy steel.—R. A. R.

FOUNDRY PRACTICE

Iron Founding in Australia. H. Dalziel. (Proceedings of the Institute of Australian Foundrymen, 1942–43, vol. 3, pp. 119–146). *See* Journ. I. and S.I., 1943, No. II, p. 10A.

Elements of Control in the Gray Iron Foundry. B. G. Russell. (Proceedings of the Institute of Australian Foundrymen, 1942–43, vol. 3, pp. 69–95). *See* Journ. I. and S.I., 1944, No. I, p. 122A.

Sodium Carbonate and Metallurgy of Iron. A. G. Lefebvre. (Bulletin de la Société Industrielle de Mulhouse, 1947, vol. 121, No. 3, pp. 31–38: [Abstract] Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Apr., p. 13). An account is given of the use of sodium carbonate in different forms in the production of cupola irons, and the soda-ash treatment of molten iron. Diagrams are given showing the fluidity of slags of the $CaO–SiO_2–Al_2O_3$ system.

New Methods of Ladle De-Sulphurising Pig Iron. W. C. Newell, A. J. Langner, and J. W. Parsons. (Institute of British Foundrymen, June 8–11, 1948, Paper No. 908). This paper is an interim report prepared by the Steel Castings Division of the British Iron and Steel Research Association for its Melting Sub-Committee upon its recent theoretical and practical enquiry for new and improved methods of desulphurizing remelted iron for iron and steel foundries. The factors examined include slag basicity, various chemically reducing conditions, agitation by gas bubbling, and the addition of specific sulphur-retaining elements such as barium. It is shown that the degree of mixing with a fluid basic slag is the predominant controlling factor and that the effect of the operation of bubbling with nitrogen is to intermix slag and metal rather than to remove the sulphur proportionately to the gas passed. The merit of sodium carbonate in providing the necessary fluid basic slag is confirmed, but it is also shown that, providing fluidity can be maintained, a highly basic calcium silicate slag can act as a substitute for soda ash. The attainment of higher desulphurizing efficiencies, theoretically possible from new desulphurizing agents, is shown to be dependent upon the practical control of slag fluidity, intermixing, and the state of reduction.

A Substitute Fuel for Cupola Use. W. J. Reagan and C. C. Wright. (Foundry, 1948, vol. 76, Aug., pp. 74–75, 138–142). A report is presented on the operation of a small cupola with anthracite as fuel. Good results were obtained with a 75/25 anthracite–coke mixture, but 100% anthracite causes the blast pressure to increase and the quantity of air to decrease. The saving in fuel cost, with coke at $22 and anthracite at $15 per ton, was substantial, and the quantity and quality of the metal produced were maintained.—R. A. R.

Some Factors Influencing the Performance of Cupola Fuels. C. C. Wright. (Iron Age, 1948, vol. 162, Aug. 12, pp. 72–77). The reactions taking place in the cupola between fuel, air, and water vapour are discussed in relation to the size and reactivity of the coke, and a graph is given which indicates the relationship between metal temperature and melting rate for various blast rates and fuel ratios for a uniform grade of foundry coke. It is stated that, as few reliable data are available on the reactivity of various types of fuel in the temperature range operative within the cupola, correction factors for other grades of coke cannot be given. J. P. S.

Theories of Gray Cast Iron Inoculation. H. W. Lownie, jun. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 837–844). *See* Journ. I. and S.I., 1945, No. II, p. 132A.

Alloy Cast Irons. A. B. Everest. (Iron and Steel, 1948, vol. 21, June, pp. 279–284). Cast iron today is regarded essentially as a mixture of a steel-like matrix and inclusions of graphite and other inclusions. From this viewpoint the author examines the effect of those alloying elements such as nickel, copper, chromium, molybdenum, and aluminium which have a definite effect on the structure of the metal; those such as tungsten, vanadium, zirconium, selenium, and tellurium which have a stabilizing effect on the carbides and those such as titanium and calcium which are used as deoxidizers but are not generally classed as alloy additions. He draws attention to the effect of alloy additions in making possible the new British Standard Specification for Grey Iron Castings, and stresses the importance of alloying elements in (1) controlling graphite form, as in the new "nodular" cast irons, and (2) producing an acicular structure in the matrix which has made possible the production of cast crankshafts. He deals also with the effect of alloying elements in producing wear-, heat-, and corrosion-resisting cast irons. J. P. S.

Improving Steel Foundry Operations. D. Clark. (Proceedings of the Institute of Australian Foundrymen, 1942–43, vol. 3, pp. 147–164). Methods of improving the steel foundry are discussed with recommendations on floor space, lighting, sand preparation, runners and risers, heat-treatment, inspection and testing, keeping records, and co-operation between men and departments.—R. A. R.

Converter Practice in a Jobbing Foundry. E. S. Playford. (Proceedings of the Institute of Australian Foundrymen, 1942–43, vol. 3, pp. 187–191). Practice at a foundry using a cupola 33 in. in dia. and two 30-cwt. Bessemer converters is described.—R. A. R.

Visits to Works. (Iron and Steel, 1948, vol. 21, July, pp. 335–342). Descriptions are given of the plant at the following works: Ealing Park Foundry Ltd., which is entirely devoted to the production of Meehanite castings; the Gothic works of R. & A. Main, Ltd., which manufacture gas appliances; Fraser and Chalmers Engineering Works; and the Ford Motor Co. Works at Dagenham.—J. C. R.

Development Programme of Davy and United Engineering Co., Ltd. (Iron and Coal Trades Review, 1948, vol. 156, June 25, pp. 1358–1364). Extensions at the Darnell works of the Davy and United Group will include a new heavy erection shop, the doubling of the heavy machine-shop capacity, the reorganization of the general machine shops, the large-scale mechanization of the foundry, the erection of a new forge and smith's shop, and the building of an apprentice school with facilities for training in fitting, fabrication, and pattern-making. At the Park Iron Works facilities for heavy

repairs and servicing will be improved, and new heavy bending rolls installed. At Glasgow, many old machine tools for the construction of steelworks plant are being replaced, and at the Middlesbrough roll foundry casting and machining capacity is being increased by, among other things, the installation of a new 15-ton electric furnace.—J. P. S.

Cupola Spout to Box Car in 75 Minutes. W. G. Gude. (Foundry, 1948, vol. 76, July, pp. 68–73, 134, 136). The Wheland Co., Chattanooga, Tennessee, operates a completely mechanized foundry on the production of automobile brake drums and clutch housings in grey and alloy cast irons.—J. P. S.

Technical Organization of the French Foundry Industry. A. Le Thomas. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 80–85). *See* Journ. I. and S.I., 1948, vol. 158, Feb., p. 268.

Mechanization for the Small Foundry. A. W. Gregg. (Foundry, 1948, vol. 76, Aug., pp. 68–73, 142–145). Descriptions are given of modern equipment for foundries producing 5 to 25 tons of castings per day, together with recommendations on machines and units which can be installed in stages as production increases.—R. A. R.

Collapsible Wire Baskets Speed Casting Handling. (Foundry, 1948, vol. 78, Aug., pp. 92–93). An illustrated description is given of collapsible square-mesh wire baskets designed to facilitate the handling of small automobile castings.—R. A. R.

Foundry Handling Set-Up Provides Fluid Production with Custom Versatility. D. Reebel. (Steel, 1948, vol. 123, July 12, pp. 93–96). The transport equipment, in which a monorail crane system and rubber-tyred lifting trucks figure prominently, at the foundry of the Eaton Manufacturing Co. is described.—R. A. R.

Canadian Steel Foundry Practice. S. L. Gertsman. (Canadian Metals and Metallurgical Industries, 1948, vol. 11, May, pp. 22–26, 40–41). Improvements in Canadian steel-foundry practice in the period 1939–1945 are reported. In particular, a procedure for melting charges of 100% high-manganese steel scrap in a basic Lectromelt furnace is described.—R. A. R.

Melting Furnaces in German Steel Foundries. H. Stein and K. Roesch. (Metallurgia, 1948, vol. 38, June, pp. 85–89). This report was prepared at the request of the British Iron and Steel Research Association. The development of steel furnaces in Germany is traced from available statistics. In general, furnace types and sizes have developed on similar lines to those in other countries. An innovation in Germany is the graphite-bar electric furnace which may replace high-frequency furnaces up to one ton in capacity for producing special high-alloys steel castings.—R. A. R.

Chemical Composition of Malleable Iron. H. A. Schwartz. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 101–115). The effects of various elements in malleable iron on graphitization and its mechanical properties are discussed on the basis of the literature and the author's own work. There are 52 references.—R. A. R.

Cores for Automotive Malleable Castings. W. G. Ferrel. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 210–212). *See* Journ. I. and S.I., 1947, vol. 156, June, p. 309.

Core Sand Purchasing Factors. H. H. Louette, A. E. Murton, and H. H. Fairfield. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 303–306). *See* Journ. I. and S.I., 1947, vol. 155, Apr., p. 629.

Malleable Core Making Practice. E. C. Zirzow. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 316–323). *See* Journ. I. and S.I., 1946, No. II, p. 89A.

Malleable Iron Foundry Core Practice. E. Welander. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 380–387). *See* Journ. I. and S.I., 1946, No. II, p. 89A.

Malleable Foundry Core Sand Practice. J. J. Clark. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 631–640). *See* Journ. I. and S.I., 1947, vol. 155, Jan., p. 149.

Some Technical Aspects of Foundry Cores. H. A. Stephens. (Proceedings of the Institute of Australian Foundrymen, 1942 43, vol. 3, pp. 1–45). *See* Journ. I. and S.I., 1943, No. I, p. 126A.

Molding Sand-Fineness Test. M. Price and A. I. Krynitsky. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 402–411). *See* Journ. I. and S.I., 1947, vol. 156, June, p. 309.

Preventing Veining and Penetration on Castings Made in Synthetic Sands. R. E. Morey and J. R. Kattus. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 129–140). The prevention of veining on castings and the penetration of the metal into the sand are discussed. Bronze, grey iron, and steel castings were studied. Veins on grey iron may form by the mould cracking under stresses set up by the growth of graphite flakes. Veining on steel castings may occur as a result of hot tears. Metal pentration can be prevented by applying a silica-flour mould wash to areas where penetration usually occurs.—R. A. R.

Gray Iron Foundry Sands. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 451–455). This is a report of the American Foundrymen's Association Sub-Committee on Physical Properties of Gray Iron Foundry Sands at Elevated Temperatures. It describes an investigation carried out to develop a quick laboratory test whereby the shakeout effort required to remove cores from castings could be measured—R. E.

High Temperature Sand Testing; Sixth Annual Progress Report. D. C. Williams. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 489–501). *See* Journ. I. and S.I., 1946, No. II, p. 47A.

Measurement and Investigation of Gases Escaping from Oil Cores. V. Volenik. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 86–92). *See* Journ. I. and S.I., 1948, vol. 158, Apr., p. 542.

Exothermic Materials. C. G. Lutts, J. P. Hickey, and M. Bock. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 337–342). *See* Journ. I. and S.I., 1947, vol. 155, Jan., p. 150.

Atmospheric and Washburn Risers. W. E. Jones. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 283–286). *See* Journ. I. and S.I., 1946, No. II, p. 88A.

Observations on Knock-Off Risers As Applied to Steel Castings. S. W. Brinson and J. A. Duma. (American Foundrymen's Association, May 3–7, 1948, Preprint No. 48-9). Several series of test castings were made of 0·20–0·30% carbon steel in green sand to study how the dimensions of the neck between riser and casting, and the dimensions of the cylindrical casting affected the soundness of the casting, *i.e.*, whether it solidified without shrinkage cavities. The maximum neck diameter was 2½ in, as the riser could not be knocked off with a sledge-hammer if the neck was any thicker. The maximum heights of vertical cylindrical castings 2, 4, 6, and 8 in. in dia. which can be adequately fed with open-top knock-off risers are 6, 8, 8, and 8 in. respectively. Castings larger than 8 in. in dia. require a riser neck too large to be knocked off with a hand-operated hammer. Several series of photographs show sections of castings and risers to demonstrate where cavities have and have not occurred with different sizes of neck and casting.—R. A. R.

A Practical Moulding Problem. J. Morley. (Proceedings of the Institute of Australian Foundrymen, 1942–43, vol. 3, pp. 193–201). Recommendations are made with regard to the casting of (*a*) a steel base plate 4 ft × 3 ft × 4 in; (*b*) gear blanks; and (*c*) railway and tramway crossings and switches in 11–14·5% manganese steel.—R. A. R.

Producing Bomb Castings by Use of the Core Barrel. B. Gray. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 70–79). *See* Journ. I. and S.I., 1946, No. II, p. 71A.

Precision Investment Casting at Allis-Chalmers. (Foundry, 1948, vol. 78, Aug., pp. 78–80, 248–252). **Precision Casting at Allis-Chalmers.** (Iron Age, 1948, vol. 161, June 3, pp. 82–85). A description is given of the equipment and processes developed by the Allis-Chalmers Manufacturing Co., Milwaukee, for the precision casting of parts by the lost-wax process.
R. A. R.

How to Prepare Metals for Precision Casting. A. K. Higgins. (Steel, 1948, vol. 123, Aug. 16, pp. 88–90). It is suggested that high-frequency induction furnaces should be used for melting metals for precision casting. Types of generator are discussed. Close metallurgical control should be exercised over raw materials and over the preparation of alloys.
J. P. S.

What the Designer Should Know about Precision Investment Casting. E. L. Cady. (Machinist, 1948, vol. 92, July 31, pp. 395–399). *See* Journ. I. and S.I., 1948, vol. 159, Aug., p. 437.

How International Nickel Makes Precision Investment Castings. (Steel, 1948, vol. 123, July 5, pp. 72–75). This well-illustrated article describes the mechanized production of small parts weighing 4 to 20 lb, in nickel alloys and stainless steels, at the Bayonne, N.J., plant of the International Nickel Co.—J. P. S.

Mechanical Shakeout. J. L. Yates. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 307–315). *See* Journ. I. and S.I., 1947, vol. 155, Feb., p. 301.

How to Seal Porous Metal Castings. P. C. Fuller. (Plastics, 1946, vol. 4, May, pp. 58, 60, 62 : [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 5–6, p. 957). An account is given of the use of a special thermo-hardening resin. Castings are impregnated under pressure or *in vacuo*, and the result obtained can be improved by an outside coating.

Nondestructive Inspection of Castings. C. L. Frear and R. E. Lyons. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 186–199). *See* Journ. I. and S.I., 1946, No. II, p. 97A.

Fluidity Testing of Foundry Alloys. K. L. Clark. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 37–48). *See* Journ. I. and S.I., 1946, No. II, p. 111A.

Steel Susceptibility to Hot-Tear Formation in Castings. N. B. Gelperin. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 724–726). *See* Journ. I. and S.I., 1946, No. II, p. 89A.

Accelerated Training. W. J. Hebard. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 184–185). American training methods for the foundry industry are discussed.—R. A. R.

Conventional Apprenticeship. C. F. Haertel. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 252–253). The author describes the indentured apprenticeships offered at the foundry with which he is connected. R. A. R.

Upgrading Learners. M. J. Gregory. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 376–377). It is recommended that the foundry foreman should have the responsibility of promoting his personnel.—R. A. R.

Skill and Leadership through Apprentice Training. J. E. Goss. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 542–544). The factors to be considered in the introduction of a successful apprenticeship scheme in foundries are considered.—R. E.

Blue-Print Reading for the Foundryman. G. D. Thompson. (Proceedings of the Australian Institute of Foundrymen, 1942–43, vol. 3, pp. 233–252). The principles of perspective, isometric, and oblique drawing are explained and the difference between British and Australian standard methods and those adopted in the United States are described. Symbols and abbreviations used on drawings are also given.—R. A. R.

Quality Control Methods. J. W. Juppenplatz. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 764–771). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 293.

Inspection—The Backbone of Quality Control. W. H. Gunselman. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 422–423). The importance of a properly trained and organized inspection department in a foundry is emphasized.—R. E.

What Management Should Know about Time Study. P. Carroll, jun. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 444–450). A plea is made for efficient and sound methods of time study in foundries. R. E.

Accident Prevention as a Function of Management. R. R. Meigs. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 225–229). A review is presented of some of the basic functions of management in the planning and execution of an effective accident prevention programme in foundries.—R. E.

Cleanliness and Order in the Foundry. W. Hanks. (Proceedings of the Institute of Australian Foundrymen, 1942–43, vol. 3, pp. 165–177). Recommendations are made on the design of foundry buildings, layout of equipment, roadways and gangways, storing patterns, reducing dust and noise, and hygiene.—R. A. R.

Hoods and Piping for Foundry Dust Control Systems. E. A. Carsey. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 479–482). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 294.

Centrifugal Dust Collectors. H. C. Dohrmann. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 597–600). The design of trap, cyclone, and volute or spiral types of centrifugal dust collectors is discussed. R. E.

Maintenance of Foundry Dust Control Equipment. K. M. Smith. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 626–630). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 294.

FORGING, STAMPING, DRAWING, AND PRESSING

Large Hydraulic Forging Presses. M. D. Stone. (Transactions of the American Society of Mechanical Engineers, 1948, vol. 70, July, pp. 499–514). The author traces the history and developments in the design and construction of large hydraulic forging presses. Particular reference is made to the design, construction, installation, and performance of two 14,000-ton presses built for the U.S. Navy. In one case an electric-drive pump system working in conjunction with a hydropneumatic accumulator is used as the power plant, whilst the other is of the steam-hydraulic type. Descriptions are also given of other heavy-stamping or die-forging presses including a 30,000-metric-ton press installed by I. G. Farbenindustrie.—J. C. R.

World's Largest Mechanical Forging Press. (Steel Processing, 1948, vol. 34, July, pp. 356–357). A very brief description is given of a forging press, weighing about 700 tons, for making forged crankshafts for motor cars.—R. A. R.

Alloying Elements and the Optimum Utilization of Mandrels for Metal-Tube Presses. H. Assmann. (Metallwirtschaft, 1948, Apr., pp. 106–114 ; May, pp. 153–157). Conditions in Germany, make it essential to use heat-treated low-alloy steels for tube-press mandrels in place of high-alloy steels. This paper deals with the stresses on mandrels and their heat-resisting requirements, the production and heat-treatment, design and expected life, and hot brittleness. The properties of high-tungsten steel and low-alloy steel mandrels are compared.—R. A. R.

Applications of Sintered Carbides to Press Tools. P. J. Papworth. (Machinist, 1948, vol. 92, Aug. 14, pp. 455–459). Rules governing the satisfactory production and uses of sintered carbide press tools are discussed.—R. F. F.

Hollow Blades for Axial Flow Compressor. R. Meredith and A. J. Phelan. (Metal Progress, 1948, vol. 53, June, pp. 841–847). The requirements for blades for axial-flow compressors are outlined, and a detailed description is given of the method developed by the Northrop-Hendy Co. for manufacturing hollow blades of 12% chromium steel sheet by forging in steel dies and arc welding.—R. A. R.

Pre-War French Experience with Steel Cartridge Cases. E. Herzog. (Metal Progress, vol. 53, May, pp. 679–683). It was found that cartridge cases could be made successfully from a 0·08–0·12% carbon steel killed with aluminium and titanium, 0·15% of copper also being added. This steel was non-ageing. It was found that, after forming into cases, tempering or stress-relieving were undesirable, giving a tendency to stick in the breech of the gun. Close tolerances and smooth non-decarburized surfaces are essential.—J. P. S.

Modern Seamless Mills. A. F. Kritscher. (American Society of Mechanical Engineers : Blast Furnace and Steel Plant, 1948, vol. 36, June, pp. 712–713). Modern types of seamless tube mills are discussed. To produce tubes up to 4½ in. in outside dia. a desirable combination would be a continuous mill for light and medium-wall thicknesses and an Assel mill to roll heavier tubes. Orders for thick-walled tubes could be rolled while the continuous mill is being changed for another size. A new development in reducing mills is the "stretch mill" in which overspeed between roll sets induces tension by which reductions in diameter of 10% to 12% per stand and reductions in wall thickness can be made. Types of tube mills for different size ranges up to 16 in. in dia. are proposed.—R. A. R.

Manufacture of Steel Tubes. H. Meyers. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, Oct., pp. 643–666). [In Portuguese].

WELDING AND FLAME-CUTTING

A Survey of Established Processes for the Jointing of Metals. D. F. Hewitt. (Sheet Metal Industries, 1948, vol. 25, Feb., pp. 363–366, 372 ; Apr., pp. 771–776, 782 ; May, pp. 991–994,

1004; June, pp. 1205–1212; July, pp. 1399–1400; Sept., pp. 1813–1821). The theory and practice of the following methods of joining metals are dealt with: Part I, soldering; Part II, hard soldering, silver soldering, many methods of brazing; Part III, gas and arc fusion welding; Part IV, atomic-hydrogen welding, the thermit process, electrical resistance, spot, butt, and flash welding; Part V, plastic bonding; and Part VI, riveting.—R. A. R.

Some Modern Developments in Steels for Welded Structures. W. Barr. (Belfast Association of Engineers: Metallurgia, 1948, vol. 38, June, pp. 79–84). Weld hardening and the Reeve cracking test are discussed and the properties of some special steels, *e.g.*, British Standard 968, Admiralty D.W, Ducol W.24, Ducol W.27, and Cor-Ten are described. The brittle fracture of welded steel ship plates is also dealt with and the effect of manganese in improving the impact strength is shown. The author recommends that the manganese/carbon ratio in steel for ship plates should be not less than 3. The proneness of Bessemer steel to brittle fracture is noted. R. A. R.

Recommendations for the Design of Arc Welded Mild Steel Machinery Constructions. (Transactions of the Institute of Welding, 1948, vol. 11, June, Welding Research, pp. 43r–53r). This comprises the recommendations of the FE7 Committee, on Design of Welded Machinery Constructions and Parts, of the British Welding Research Association, and covers fillet and butt welds, working stresses, design and details, and the information required for manufacture.—J. P. S.

The Present Position on Residual Stresses in Welded Structures. R. Weck. (Transactions of the Institute of Welding, 1948, vol. 11, Aug., pp. 142–147). Three different types of failure are associated with residual stresses in welded structures, occurring (1) during or shortly after welding, (2) in service, and (3) under the influence of corrosive media. All have the common feature of absence of plastic deformation. The author concludes that residual stresses will not influence the static load-carrying capacity of a structure, and that stress-relieving heat-treatment will not increase the strength, safety, or serviceability of a welded structure.—J. P. S.

Contact Arc Welding. (Werkstatt und Betrieb, 1948, vol. 81, Aug., pp. 221–222). The contact method of welding discussed by P. C. van der Willigen is described (*see* Journ. I. and S.I., 1946, No. II, p. 135A).

Automatic Welding with a Three-Phase Arc. G. P. Michajlov. (Avtogennoe Delo, 1948, No. 3, pp. 18–21). [In Russian]. Welding experiments with a three-phase arc are described. These arcs are between the individual electrodes and between the electrodes and the welded material. By regulation of the current of the individual electrodes and their relative positions the arcs can be adjusted to obtain optimum welding conditions. It is possible to cause the arcs to burn mainly between the electrodes and the parent material to obtain deep penetration, or to make them burn mainly between the electrodes, thus melting less of the base material and depositing more weld metal from the electrodes. The possibility of regulating the heat supply permits welding of various sheet thicknesses, of special steels and non-ferrous metals. Mechanical, chemical, and metallographical tests proved that the quality of the welds was very good.—E. G.

Novel Developments in Design and Operation of A.C. Welding Plant. E. C. Davies. (Transactions of the Institute of Welding, 1948, vol. 11, June, pp. 92–96). This paper describes some new developments in welding, such as application of isolating gear to reduce risk of shock, the use of the "pilot arc" in non-ferrous welding, and the use of the multi-phase arc and controlled automatic welding.—J. P. S.

Steady Flow of Current of the Electric Arc during Welding. V. P. Nikitin. (Bulletin de l'Académie des Sciences, Classe des Sciences Techniques, 1947, No. 10, pp. 1315–1322).

The Sequence of Welding Passes in Welded Seams. W. Bonhomme. (Revue de la Soudure/Laschtijdschrift, 1947, vol. 3, No. 4, pp. 175–187; 1948, vol. 4, No. 1, pp. 29–35; No. 2, pp. 70–75). Conclusion of a series of articles. *See* Journ. I. and S.I., 1948, vol. 158, Mar., p. 402.

High-Speed Photography of Welding Arcs. F. Brailsford and K. F. Shrubb. (Journal of Scientific Instruments, 1948, vol. 25, June, pp. 211–213). This paper describes a high-speed camera for photographing the transfer of metal in the welding arc. Forty-five pictures are taken in one run, at the rate of 2500/sec. The rotating drum carries only one length (25 in) of film, as an endless band, thus avoiding wastage during acceleration; the optical compensator, which causes the image to travel with the film during exposure, is a rotating glass prism.—J. P. S.

Arc Welding Equipment and Electrodes and Welding Applications in Germany. (British Intelligence Objectives Sub-Committee, 1948, Final Report No. 1750: H.M. Stationery Office). A report is presented on visits to German works manufacturing welding electrodes, together with details of arc-welding plant and illustrations of arc-welding applications. There is little improvement since 1939 in the machinery for making electrodes.—R. A. R.

The Present German Technical Position with Regard to Weldable Ferrous Materials and the Supplementary Materials Required. K. L. Zeyen. (Werkstatt und Betrieb, 1948, vol. 81, Aug., pp. 216–218).

Construction and Maintenance of Railroad Equipment by Submerged and Gas-Shielded Electric Welding. N. G. Schreiner and J. M. Tippett. (Welding Journal, 1948, vol. 27, June, pp. 431–437). The principles of submerged-arc and gas-shielded arc-welding processes are explained, and their application to the production of rail tank-cars, locomotive boilers and fire-boxes, and in the building up of various worn parts are described and illustrated.—J. P. S.

Manual Hidden-Arc Welding Cuts Welding Time by 65%. E. A. Hess. (Iron Age, 1948, vol. 162, July 8, pp. 78–79). Manual hidden-arc welding is now used by the Bucyrus Erie Co. in the manufacture of large girders, for dragline excavators, 6 ft high and 40 ft long. No edge preparation is necessary and welding is up to four times as fast as previous hand methods.—J. P. S.

Manual Hidden Arc Welding Increases Welding Speeds. R. Zeh. (Steel Processing, 1948, vol. 34, July, pp. 358–359). The "Manual Lincolnweld" machine is described and illustrated. This is a portable electric-welding unit with automatic wire-feeding mechanism and equipment for feeding the granular flux on to the work.—R. A. R.

Multiple Welding Procedures. E. O. Courtemanche. (Steel, 1948, vol 122, June 14, pp. 93–95). The development of modern automatic resistance welding machines is outlined. M. A. V.

Resistance Welding in the Steel Industry. O. H. Griffith. (Iron and Steel Engineer, 1948, vol. 25, July, pp. 58–61). Resistance welding machines for spot, seam, and flash-butt welding steel, as one of the operations in a continuous process, are described.—R. A. R.

Functionalised Electronic Controls for Resistance Welding. W. E. Large. (Iron Age, 1948, vol. 162, July 8, pp. 90–94). Resistance-welding control gear has been constructed in the form of light main units and six supplementary assemblies; by suitable combinations of these a great variety of welding times and sequences may be obtained.—J. P. S.

Two Methods of Estimating the Weldability of Metals by Resistance Measurement. W. S. Simmie. (Sheet Metal Industries, 1948, vol. 25, July, pp. 1407–1409). In the spot-welding of sheet metal the electrodes pick up metal and have to be dressed frequently if there is oxide on the sheet which causes overheating. A simple electrical resistance test has been devised so that a rapid assessment can be made of specimens from the pickling bath, and, if their resistance is less than a previously established value, it will be known that the remainder of the batch of pickled sheet can be satisfactorily welded. Details of this resistance test, using low or high mechanical pressure on the electrodes, are given.—R. A. R.

Welding Dissimilar Metals with Stainless Electrodes. A. L. Schaeffler. (Iron Age, 1948, vol. 162, July 1, pp. 72–79). The author has developed a graphical method for determining the conditions under which alloy steels may be welded to mild, or lower alloy steels; it employs chromium and nickel equivalent values and makes possible a consideration of most of the elements affecting microstructure.—J. P. S.

Hard Facing Improves Tool Life. L. Barrett. (Machinist, 1948, vol. 92, July, 10 pp. 314–315). This describes the use of chromium borite (boride ?) for building up worn and scored parts such as expansion mandrels, by powder spraying. The coating is subsequently bonded by a torch flame or by induction heating.—J. P. S.

Some Considerations in Hard Surfacing. D. B. Rankin. Iron Age, 1948, vol. 161, June 17, pp. 91–93). The advantages of welding a layer of wear-resistant alloy on to parts subjected

to severe abrasion are outlined, and the selection of a suitable alloy and the relation of cost to performance are considered. R. A. R.

Butt Welded Chains. (Welding, 1948, vol. 16, June, pp. 230–235, 248). The Parsons Chain Co., Ltd., Stourport, Worcester, manufactures electrically butt-welded chains from 0·18–0·23% carbon steel, and is developing the process for use on higher alloy and stainless steels. Welding is a fully automatic slow butt-weld process. Heat-treatment is carried out in continuous producer-gas furnaces, and non-skid chains are case-hardened. After heat-treatment, chains are tested to 100% overload.—J. P. S.

Automatic Welding of Steel Mill Equipment. W. W. Scherer and H. J. Ralston. (Iron Age, 1948, vol. 162, July 15, pp. 80–88). The installation set up by Carnegie-Illinois Steel Corp. at Homestead, Pa., for the repair of heavy steel-mill plant is described. Automatic flux-covered arc welding is used, and its application to the building up of roll journals and the repair of heavy shafts is illustrated.—J. P. S.

How to Weld Clad Steels. L. W. Williams. (Iron Age, 1948, vol. 162, July 22, pp. 72–80 ; July 29, pp. 82–88). Details are given of methods of welding plates clad with stainless steel, nickel, and Monel metal, in various gauges and in a number of applications such as butt welds, **T**-joints, and the construction of tanks and vessels.—J. P. S.

Metallurgical Aspects of Cast Iron Repair Welding. J. M. Diebold, J. A. Blastic, and J. A. Griffin. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 343–356). *See* Journ. I. and S.I., 1947, vol. 155, Feb., p. 309.

Welding and Salvage of Gray Iron Castings. J. A. Griffin. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 412–419). *See* Journ. I. and S.I., 1946, No. II, p. 97A.

Welding Heavy Gray Iron Castings. L. J. Larson. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 601–609). *See* Journ. I and S.I., 1947, vol. 156, June, p. 313.

Practical Application of Cast Iron Weld Repair Methods. W. J. Pfander. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 780–790). *See* Journ. I. and S.I., 1947, vol. 157, Sept., p. 148.

Some Essentials in Oxy Acetylene Pipe-Line Welding. E. Fuchs. (Welding, 1948, vol. 16, June, pp. 236–248). This article describes the correct preparation for butt-welding of pipe ends, and for the joining-on of branches.—J. P. S.

Brazing and Other Applications of High Frequency Heating. H. Bunte. (Welding Journal, 1948, vol. 27, June, pp. 441–444). The advantages of induction heating for providing heat at surfaces or concentrated in areas are outlined, the generating equipment is described and some applications mentioned.—J. P. S.

The Relation between Bending Angle and Specimen Thickness in Bend Tests on Welded Specimens. N. Ludwig. (Werkstatt und Betrieb, 1948, vol. 81, July, pp. 181–183). The results obtained in bend tests on welded specimens depend on several factors one of which is the thickness of the specimen. A series of weld bend tests was carried out on specimens of manganese steel (C 0·18–0·20%, Mn 1·03–1·27% with small amounts of copper and chromium) on specimens 6, 12, 15, 25, 30, 40, 45, and 50 mm thick. In general, the bending angle up to fracture decreased with increasing thickness ; the smallest angle was in the 30–40 mm range, but no explanation for this was found.—R. A. R.

The Powder Process in Stainless Steel Production. C. J. Burch and E. M. Holub. (Iron and Steel Engineer, 1948, vol. 25, July, pp. 43–52). A description is given of the hand and machine processes of cutting stainless steel with the oxy-acetylene torch into the flame of which a stream of fluxing powder is directed. Data on cutting speed, nozzle size, oxygen pressure, and powder consumption are given.—R. A. R.

MACHINING AND MACHINABILITY

Recent Research on the Metal-Cutting Process. M. I. Klushin. (Stanki i Instrumenty, 1947, vol. 18, No. 1, pp. 15–21). [In Russian]. The following aspects of machining are discussed : (1) Stresses arising in the machined part ; (2) mechanism of chip formation ; (3) forces acting on the cutting tool ; (4) influence of tool angle and depth of cut on chip formation ; and (5) influence of cutting speed and depth of cut on length of chip, tool life, and power requirements. The employment of photography to check machining theories is also dealt with. E. G.

Some Aspects of Metal Cutting Tools. A. G. Denham. (Australian Institute of Metals : Australasian Engineer, 1947, Apr. 8, pp. 61–68). Methods of improving the life of and diagnosing failures in tungsten–chromium–vanadium high-speed steels are discussed. Electric salt-bath furnaces are recommended for high-production heat-treatment. Nitriding certain gear cutters and taps is recommended. Chromium plating high-speed steels for cutting copper or any material likely to weld on to the cutting faces is advocated. Colouring makes tools more rust-resisting, but does not affect the wear. Examples of a variety of tool failures with diagnosis of the causes are cited.—R. A. R.

The Growth of High-Speed Steel and Related Alloys During the Past 25 Years. W. R. Hardwick. (Alloy Metals Review, 1948, vol. 6, June, pp. 2–8). This article describes the development of high-speed steels, reviews the wartime substitutes and notes the return to three basic pre-war types, *i.e.*, 18% W, 4% Cr, 1% V, and the same with 5% and 10% Co. The use of Stellite, and the possibilities of precision-casting high-speed steels into tool forms are also mentioned.—J. P. S.

On the Utilization, Maintenance and Repair of Machine Tools. A. P. Vladizevskij. (Stanki i Instrumenty, 1946, vol. 17, Dec., pp. 16–24). [In Russian]. This contains individual contributions to a discussion of a paper of the same title published in an earlier issue. Maintenance of machine tools and compliance with technical instructions on operation of the individual types of machines, the provision of spare parts, and the systematic checking and repair of machine tools are considered. E. G.

Present State of Development of the Use of Accessories on Machine Tools. I. Z. Zajchenko. (Stanki i Instrumenty, 1947, vol. 18, No. 1, pp. 11–15). [In Russian]. Grinding and honing machines are discussed. Requirements to be met by the hydraulic equipment on the various individual types of machine tools, and descriptions of the current hydraulic machine-tool equipment, their functioning, and properties are given. Test results obtained with the Soviet machine tools 315 M and 372 AM are shown.—E. G.

Requirements to Be Met by Lathes Working with Hard-Tip Tools. J. Píč. (Technické Zprávy Československých závodů Kovodělných a Strojírenskych, 1947, Aug., pp. 69–78). [In Czech]. Hard-metal-tipped tools are much more brittle than high-speed steel tools, and are very sensitive to shocks and vibration. Lathes for using the former tools must be particularly rigid and the older designs are not very suitable. The correct design is discussed and some lathes of recent design at the Skoda works are described.—E. G.

" Meccano " Design of Lathes. B. L. Boguslavskij. (Stanki i Instrumenty, 1947, vol. 18, No. 1, pp. 3–10). [In Russian]. The importance of the " Meccano "-type design of lathes and lathe groups and general principles of their design are explained. The present state of development, mainly in the U.S.S.R. is discussed. The method applied for type standardization of lathe groups and some tabulated data of the main types recommended for standardization, together with recommendations on further standardization are given.—E. G.

Cutting of Hard Castings and Steel by the Electro-Erosive Method. T. P. Rekshinskaja. (Avtomobilovi Promyshlennost, 1946, No. 5–6, p. 12). [In Russian].

Heat Conditions during Grinding. B. I. Kostecký. (Vestnik Mashinostroeniya, 1947, vol. 27, No. 1, pp. 36–43). [In Russian]. This paper gives a description of a method of determining the temperature conditions during grinding from the microstructure of the surface layers of ground objects. The determination of the speed of temperature increase of the ground surface, the temperature of the surface and strength of the ground material at that temperature, the cooling speed, and the temperature distribution in the ground object are considered.—E. G.

Machining of Metals by the Electric Spark Method. B. R. Lazarenko. (Vestnik Mashinostroeniya, 1947, vol. 27, No. 1, pp. 25–36). [In Russian]. This paper describes the limitations of the mechanical machining of metals, and machining by electric spark based on the principle of erosion of material by electricity. The main parts of the new machine tools, boring and engraving machines, and the field of application of the two types of machines are explained, together with the

conditions under which various materials can be machined according to this new method. The machining speed, surface quality and working accuracy are given.—E. G.

Machining of Metals by the Electric Spark Method. B. R. and N. I. Lazarenko. (Stanki i Instrumenty, 1946, vol. 17, No. 12, pp. 8–11; 1947, vol. 18, No. 2, pp. 4–8). [In Russian]. This paper describes: (1) Basic principles of the electro-erosion method. (2) Work with and without electrolytes. (3) The formation of metal powder during the machining operation. (4) Metal coating with electric sparks. (5) Cleaning of the surface, engraving, and boring of holes. (6) Schematic circuit diagram. (7) Working speed and methods applied for increasing it. The prospects of increasing the practical application of this method of machining and possibilities of building current types of machine tools working on the electro-erosion principle are discussed.—E. G.

Mirror Finishing [Grinding] a Chromium-Plated Roll. L. E. Paine. (Grits & Grinds, 1948, vol. 39, Apr., pp. 8–10).

Superfinishing. (Commisariat Général aux Économies de Matières, Bulletin No. 8: Métaux, Corrosion, Usure, 1945, vol. 20, Feb., pp. 25–27). A general account is presented of the technique and advantages of superfinishing metal surfaces. J. C. R.

High Precision Surface Finish Standard To Be Offered Metal Processing Industry. C. R. Lewis and A. F. Underwood. (Steel, 1948, vol. 123, July 19, pp. 90–92, 124). The methods employed by the General Motors Corp. in the production of sets of steel specimens as standards of surface roughness are briefly described. The problem involved designing a scribing machine to rule up to 10,000 lines per inch with a pitch accuracy of $\pm$ 2%.—R. A. R.

A Refined Metallographic Technique for the Examination of Surface Contours and Surface Structure of Metals. A. J. W. Moore. (Metallurgia, 1948, vol. 38, June, pp. 71–74). A detailed account is given of a taper-sectioning technique for examining surface contours and structures of metals. Provided that the surface irregularities are elongated in one direction, a section cut obliquely to the surface will produce a taper section with the vertical component of the surface contour greatly magnified relative to the horizontal one.—R. A. R.

O.P.L. Direct-Vision Surfascope. (Mesures et Contrôle Industriel, 1948, vol. 13, Mar., pp. 99–101: [Abridged Translation] Engineers' Digest (London) 1948, vol. 9; July, p. 239). The "surfascope," used for the optical measurement of roughness of plane or cylindrical metal surfaces, is described and methods of operation are given.—R. F. F.

Survey of the Industrial Problem of Geometric Irregularities of Surfaces. P. Nicoleau. (Machines et Métaux, 1948, vol. 59, May, pp. 184–192). The work of various investigators is reviewed. A bibliography of 30 references is appended. R. F. F.

Sharp Edges. Determination of Their Dimensions. J. F. Kayser. (Iron and Steel, 1948, vol. 21, July, pp. 325–328). A review is presented of the work of various investigators on the exact measurement of the sharpness of cutting edges with particular reference to razor blades. The author includes an account of his own method for determining the radius of curvature of a razor blade or for determining an upper limit for its thickness, by means of interference fringes. By this method the thickness of some of the sharpest safety razor edges has been found to be less than 0·5μ.—J. C. R.

Roughness Measurements with the Electron Microscope. R. Seeliger. (Zeitschrift für Metallkunde, 1948, vol. 39, June, pp. 170–172).

CLEANING AND PICKLING

The Theory and Practice of Metal Degreasing in Aqueous Media. P. D. Liddiard. (Chemistry and Industry, 1947, July 10, pp. 435–437). Metal cleaning is studied from the scientific angle and some accepted features of the process are questioned. Degreasing is shown to be a combination of chemical, physical, and mechanical processes. Emphasis is now on wetting of the metal by the degreasing solution rather than the deposit. Subsequently the oil should be emulsified to prevent it rising to the top of the solution and contaminating the metal on removal. Of alkaline solutions the silicate group holds a unique position. The more siliceous silicates may be very alkaline with considerable ionization in solution, but they can also form charged micelles having a considerably greater mass than that of the anions of other alkalis. More attention should be given to the choice of surface-active agents. The rinsing action of caustic soda is not very good but it can be greatly assisted by the presence of as little as 0·001% of sodium hexametaphosphate. Conditions promoting corrosion often exist in the cleaning bath, but it is the presence of oxygen in solution which promotes the greatest attack. More attention to wetting will assist in promoting faster cleaning, but far more needs to be known of the true detergent equence before revolutionary changes will be seen.—R. A. R.

Carbon Brick Tank Linings Used for Pickling Stainless Steels. (Steel, 1948, vol. 123, Aug. 2, pp. 101, 104–106). Carbon brick has been successfully used to line tanks for the pickling of stainless steel; the tanks contain 23–40% HNO_3 and 3–6 % total fluorides, at temperatures of 140–160° F (60° to 70° C); Basolit or Carbo-Vitrobond cement is used between the courses, while the outer steel tank is internally coated with Koroseal or pitched and coated with a sulphur-base acid-resistant paint. Graphite heat-exchangers are used for heating.—J. P. S.

Flame Cleaning: Ally against Corrosion. (South African Welder, 1948, vol. 1, June, pp. 9–13). The procedure for flame cleaning steel is described and its advantages as a means of preparing the surface for painting are pointed out.—R. A. R.

The Flame Cleaning Process. (Overseas Engineer, 1948, vol. 22, Aug., pp. 3–5). The equipment and procedure for flame cleaning and descaling are described and illustrated. Its advantages as a means of preparing steel for painting are pointed out.—R. A. R.

Electrolytic Descaling. C. A. Zapffe. (Metal Progress, 1948, vol. 53, June, pp. 833–836). Further evidence is submitted in support of the theory that, when steel to be descaled is made the cathode in an electrolyte, atomic hydrogen enters the planar imperfections of each crystal and diffuses along the planes of crystalline symmetry, the gas pockets breaking from one domain into another. The movement of these gaseous occlusions to surfaces underlying scale adjacent to the absorption areas blasts off, or initiates blasting of the overlying scale.—R. A. R.

PROTECTIVE COATINGS

The Testing of Electrodeposited Coatings. W. F. Troescher. (Werkstatt und Betrieb, 1948, vol. 81, July, p. 184). Details are given of the potassium ferricyanide test for determining the porosity of electrodeposited coatings on iron, copper, and alloys, and of a copper sulphate test for determining the thickness of zinc coatings.—R. A. R.

Evaluation of Surface Coatings by a New Sectioning Procedure. H. Klemm. (Archiv für Metallkunde, 1948, vol. 2, Jan. pp. 12–15). A description is given of a method of measuring the thickness of electroplated coatings in which the specimen is embedded in a material, made by powder-metallurgy, of approximately equal hardness to the base metal; a section is then cut obliquely (at say 20°) to the plated surface. The section through the plating is measured with a microscope at 500 diameters and the true thickness is then calculated.

Technical Data on Electronic Micrometer. (Electronics, 1947, vol. 20, Nov., pp. 172, 174, 176, 178, 180). This micrometer enables films 0·127 mm thick to be measured within an accuracy of 1μ.

Strip Tension and Velocity Control. C. Diechert. (Steel, 1948, vol. 123, July, 26, pp. 69–70, 102). A zinc-plated and phosphatized finish is required for steel strip intended for stamping into venetian-blind slats to be subsequently painted. Uniform tension and controlled velocity during the pickling, plating, phosphatizing, and re-coiling are provided by differential and other gear mechanisms.—J. P. S.

Bright Zinc Coatings on Iron. A. Luis Palomo and J. H. Faura. (Afinidad, 1947, vol. 24, pp. 161–163: British Abstracts, BI, 1948, June, col. 241). The effect of *p*H, temperature, bath composition, and current density on the deposition of electrolytic zinc coatings on iron from aqueous $ZnSO_4$ has been studied. These variables are closely interrelated, but the brightness of the coatings appears to depend on the rate of evolution of hydrogen at the cathode.

Testing of Zinc Coating on Wire. B. Hošna. (Electrotechnický Obzor, 1948, vol. 12, June, pp. 243–251). [In Czech.] The Preece test is briefly described and it is pointed out that this method is inaccurate. The salt-spray test requires

too much time and the result is greatly influenced by the interpretation of the operator. A third method is now being widely introduced in which the zinc layer is chemically removed and the zinc obtained weighed. This led to the development of the hydrogen test, where the hydrogen developed is measured and from this the amount of zinc is calculated. Vondráček has developed a relatively simple test arrangement using a solution of 49 g of H_2SO_4 per litre of water and a light petrol, alcohol-ether, or some similar solution, for removing grease from the samples. The apparatus enables determinations of the thickness and the quality of the zinc layer to be made. If the layer thickness only is of interest it is necessary only to measure the total quantity of the hydrogen developed in the test tube after the bubble generation on the wire surface has ceased. It it is also desired to test the quality of the zinc layer, readings of the hydrogen developed have to be taken every minute till no more than 0·1–0·2 cu.cm./min of hydrogen is generated. The characteristic of the curve obtained gives a clear indication of the quality of the zinc layer and repetitive tests give nearly the same results. It is also possible to distinguish between galvanically coated and hot-dipped wires, because the characteristic curves differ markedly. The quality of the coating is better with increasing ratio of the times for dissolving half and the whole of the coating. The disadvantage of this test arrangement is that a new solution of the same concentration is required for each test; it is also time-consuming. These disadvantages are eliminated in the apparatus of Keller and Boháček which is briefly described. HCl is used, with an addition of 10 cu.cm. of $SbCl_3$ as an inhibitor. Hydrogen evolution starts immediately after the sample is dropped into the test tube and is complete in 1–3 min, depending on the saturation of the solution. The solution can be used several times, and when it is saturated with zinc, fresh solution is added. Tables are compiled enabling quick calculation of the weight of the zinc layer per square meter for various wire diameters and hydrogen quantities to be made and nomographs are presented for rapidly calculating the weight of zinc per square metre. Very accurate results are obtained by this method. The uniformity of the coating is not determined by this method.—E. G.

Continuous Coating. F. M. Morrow and K. Oganowski. (American Iron and Steel Institute, 1948, May 26–27, Preprint). Continuous galvanizing at the works of the Armco Steel Corp. is described and the capacities and general merits of three types of plant are discussed. These types are: (*a*) The converted sheet unit with uncoiling and shearing equipment as the major items of additional equipment; (*b*) the converted sheet unit with the addition of uncoiling, looping, coiling, and shearing equipment; and (*c*) the continuous line in which the wide strip is processed directly from the cold reduction mill.—R. A. R.

Tinplate Printing Plant. H. Ratcliff. (British Engineering Export Journal, 1948, vol. 31, Aug., pp. 291–296). After a short explanation of lithography the development of machines for printing on tinplate is described with illustrations of many of the machines now used for this purpose. R. A. R.

Tin-Stack Firing System at T.C.I. a Model of Control and Economy. (Industrial Heating, 1948, vol. 15, June, pp. 980–984). Brief details are given of the tinning plant at the Tennessee Coal, Iron and Railroad Co, where the tin baths are heated by immersed combustion tubes.—R. A. R.

Description of New Plant—The Ferrostan Electrolytic Tinning Line at Richard Thomas and Baldwins Ltd., Ebbw Vale. (Journal of The Iron and Steel Institute, 1948, vol. 159, July, pp. 297–314).

Aluminium Coating of Steel. A. Di Giulio. (Light Metal Age, 1948, June, pp. 8–9). A process of coating steel parts with aluminium is described. It is carried out in the following stages: (1) Degreasing in a solvent; (2) pickling; (3) rinsing and drying; (4) immersing in molten flux held at about 750° F for 3–6 sec; (5) dipping in molten aluminium which floats on electrically heated molten salt held at 1300–2000° F; and (6) shaking off excess aluminium and quenching in water or oil at 100° F.—R. A. R.

Hot Aluminium Coating of Steel. M. Alférieff. (Métaux, Corrosion, Usure, 1945, vol. 20, May, pp. 60–68). In this method steel strip, after cold rolling, is annealed in the presence of various gases which enable a clean surface to be obtained, and then immersed in a bath of molten aluminium (99·5% pure). A coating composed of the two metals forms immediately on the surface of the strip, and when the strip is removed from the bath an extra coating of pure aluminium forms outside the other coating. The coatings when examined by X-rays showed the following phases: Solid solution of aluminium in iron; a superstructure of Fe–Al and Fe–Al_2; an unidentified phase, probably Fe–Al_3; the Fe–Al_3 phase; finally, aluminium. Brief reference is made to mechanical properties and some notes are given on mechanical working of this metal.—J. C. R.

Bonding Aluminium to Ferrous Metals. M. G. Whitfield and V. Sheshunoff. (Modern Metals, 1948, vol. 4, Apr., pp. 13–15: Iron Age, 1948, vol. 162, July 1, pp. 88–93). Aluminium may be bonded to steel or cast iron by casting it round the part which has been previously coated with tin, zinc, or aluminium. Aluminium sheet may also be brazed to aluminium-coated steel sheet. The bonding layers in all cases tend to be brittle but possess great compressive, and reasonable tensile, strength. Assemblies can be formed having high mechanical strength and good thermal conductivity. J. P. S.

Report on Experience in the Protection of Materials by Sprayed Aluminium Coatings. M. Haas. (Metallwirtschaft, 1948, Feb., p. 35). Applications of sprayed aluminium coatings are cited. Where peeled potatoes are carried in quantity, metal baskets coated with aluminium are considered better than tin-coated steel—R. A. R.

A New Method for Combating Rust and Simultaneously Passivating Iron. (Österreichischer Maschinenmarkt und Eisenhandel, 1948, vol. 3, June, p. 177). The "Ferro-bet" method of treating the surfaces of steel structures which cannot be dipped in a bath is described. This consists of brushing off loose rust and painting or spraying on a phosphatizing solution (Ferro-bet). This forms a fine crystalline layer of complex phosphates on the steel which prevents rust formation and gives good adhesion to subsequent paint coating.—R. A. R.

Electro-Zinc Phosphate Coatings for Iron and Steel. E. E. Halls. (Metallurgia, 1948, vol. 38, May, pp. 34–36). Electro-zinc phosphatizing is carried out by alternating current. The composition of the electrolyte is not specified, but the treatment produces a dark-grey coating, composed mainly of a zinc phosphate in intimate bond with the base material. This process gives, in some cases, a coating more corrosion-resistant than either a plain phosphate coating on the base metal or a phosphate treatment of electrodeposited zinc. It provides a good key for the adhesion of organic coatings of oil, lacquer, or enamel.—J. P. S.

Properties and Applications of Phosphatizing. (Métallurgie, 1948, vol. 80, May, p. 41; June, pp. 30–31). A brief survey of the phosphatizing process and its applications is presented. J. C. R.

Improving the Adhesion of Organic Finishes over Zinc Plate. R. E. Kohl. (Materials and Methods, 1948, vol. 27, May, p. 83). A 'commercially available' chromate solution, containing formic acid, is used as a dip immediately after electrolytic zinc plating on steel, and provides good adhesion in conditions of heat, cold, and humidity.—J. P. S.

Organic Coatings for Corrosion Protection. A General Discussion. G. W. Seagren. (Corrosion, 1948, vol. 4, May, pp. 219–226). An organic coating material must be continuous and of low permeability, it must resist the spread of corrosion from unprotected areas and not be degraded by its environment. The author discusses, in the light of these four desirable characteristics, synthetic resins, resins pigmented with aluminium, and silicone resins.—J. P. S.

Copper-Covered Steel Proves Useful for a Variety of Applications. H. A. Knight. (Materials and Methods, 1948, vol. 27, May, pp. 75–77). A variety of applications for copper-clad steel rod and wire are described—fencing material, costume jewellery, nails, etc. The material is made by casting electrolytic copper round bars of a special forging-quality manganese steel in graphite moulds; the composite ingot is then reheated to a carefully chosen rolling temperature, rolled down to bar, and if necessary, drawn down to wire. Tensile strengths, in wire, may run to 80 tons/sq.in., and electrical conductivity to 30–40% of the equivalent diameter in copper.—J. P. S.

How Metallizing Solves Mine Maintenance Problems. R. Mansell. (Engineering and Mining Journal, 1948, vol. 149, July, pp. 82–84). Examples are given of the application

of metal spraying for the repair of mining machinery.—R. A. R.

The Structure of Sprayed Metal Coatings. H. Reininger. (Metalloberfläche, 1948, vol. 2, May–June, pp. 97–111). The structures of sprayed metal coatings are described and illustrated, with 92 references to the literature and patents. Sprayed coatings have a characteristic structure. If the sprayed metal has a low melting point and the base metal is preheated, the coating can form a complex structure before solidifying whilst the surface particles sinter together in the plastic state. The force of the impact causes interlocking with adjacent particles and contributes to the strength of the coating. The coating does not form an alloy with the base metal and the surface of the latter must therefore be roughened; methods of doing this are described. The structure and adherence of the coating can be improved by heat-treatment and examples of this are also described.—R. A. R.

Refractory Ceramic Base Coats for Metal. W. J. Plankenhorn. (Journal of the American Ceramic Society, 1948, vol. 31, June 1, pp. 145–153). Ceramic coatings were developed for the protection of ingot iron, low-carbon steel and alloys at high temperatures (up to 2500° F). Diaspore proved the most suitable of mill additions which were studied to improve the effectiveness of the coatings produced from various frit glasses. To improve the heat-resistant properties of ceramic coatings and their suitability for various base metals, formulæ of special frit glasses were investigated; tables show the results obtained. Sand-blasting proved the most suitable method of preparation for coating. Results of service tests are discussed.—R. F. F.

The Adhesion of Enamel Finishes to Electro-Plated Cadmium Coatings. E. E. Halls. (Metallurgia, 1948, vol. 38, June, pp. 75–78). Cadmium-plated steel panels were treated by various forms of chromate and phosphate passivation and then enamelled; the panels were then subjected to exposure, scratch, and bend tests. The results are given in several tables. Where enamel adhesion is the important factor, phosphate treatment appeared to be superior to chromate treatment.—R. A. R.

Industrial Enamelling of Metals in the Electric Furnace. M. R. Nalgat. (France Energétique, 1947, Jan.–Feb., Mar.–Apr., pp. 23–32: [Abstract] Revue Universelle des Mines, 1948, Series 9, vol. 4, Aug., pp. 479–480).

Extrusion Method of Plastic Finishing Steel Tubing. (Steel, 1948, vol. 123, July 19, p. 104). An extrusion method of applying a $\frac{1}{32}$-in coating of cellulose acetate butyrate to steel and non-ferrous metal tubes is described and illustrated. R. A. R.

Vinyl Polymers in Surface Coatings. C. W. Patton. (Official Digest of the Federation of Paint and Varnish Production Clubs, 1948, No. 278, pp. 267–279: Chemical Abstracts, 1948, vol. 42, June 20, col. 4368). Patton discusses the basic technology of formulating vinyl resins into a protective coating, its uses, and compatibility with various solvents. The chemical and physical properties of vinyl-chloride/vinyl-acetate resins are described, and a chart containing solubility characteristics is included. A summary of actual test results with vinyl butyral 'wash primer' is given. Marine systems based on the vinyl-chloride/vinyl-acetate resin/rosin/cuprous-oxide topcoat, strongly adhering to the vinyl butyral 'wash primer' (which prevents creeping of corrosion under exposed edges of the paint film), have protected metal in salt water for thirty months to date.

Report on the Evaluation of Surface Treatment of Steel Prior to Painting. (Proceedings of the American Society for Testing Materials, 1947, vol. 47, pp. 264–270). *See* Journ. I. and S.I., 1948, vol. 159, June, p. 226.

Acid-Resisting Paints and Lacquers. A. Kufferath. (Metalloberfläche, 1947, vol. 1, June, pp. 140–141). Recommendations are made on the composition of paints, synthetic resins, and lacquers for protection against attack by different acids.—R. A. R.

Developments in Electrostatic Paint Spraying. (Electroplating, 1948, vol. 1, July, pp. 449–451). An account is given of the electrostatic paint-spraying process which enables a coating of even thickness to be obtained and effects a considerable economy in the use of paint. The plant used is described and illustrated.—J. C. R.

Primers for Ferrous Metals in an Atmospheric Exposure. III. New England Paint and Varnish Production Club. (American Paint Journal, Daily Convention, 1947, vol. 32, No. 7D, pp. 23–29: British Abstracts, 1948, BII, June, col. 200). This is a progress report. A series of paints has been applied to cold-rolled Pangborn, hot-rolled angles, electrolytic zinc, and ingot-iron panels. Physical constants of the paints are reported, but no weathering results are available.

The Use of the Spray Gun for the Painting of Metal Structures after the War. (Association pour la Protection des Surfaces: Métaux, Corrosion, Usure, 1945, vol. 20, Jan., pp. 5–14). In this report the possible developments in France in the spray-gun painting of metal structures are considered. Particular attention is paid to the quality of the work and the completeness of the protection provided. Estimated operating costs of brush and spray-gun painting are compared.—J. C. R.

Rust, Industry's Arch Enemy. T. Trail. (Power Plant Engineering, 1947, vol. 51, June, pp. 84–86: [Abstract] Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Mar., p. 32). The theory of the formation of rust is explained and the conditions that protective coatings must fulfil are outlined. The use of pigments which promote the even spreading of the coatings is reviewed. Attention is also given to the following points: Preparation of surfaces before painting; special treatment of galvanized iron; paints used for different metals.

An Investigation into the Adhesion of Paint to Metal Surfaces. S. C. Britton. (Sheet Metal Industries, 1948, vol. 25, June, pp. 1185–1190, 1194). A method is described for obtaining quantitative data on the adhesion of lacquer films to metal so as to study the effect of surface-roughening treatment before lacquering. Two parallel cuts 2 cm apart were made through the lacquer on specimen plates. A short tongue of the film was peeled off, and, with the lacquered side downwards on a stand, a clip carrying a fine wire and a scale pan was attached to the tongue. Weights were placed in the pan and curves plotted for the weight and speed of peeling. Phosphatizing or galvanizing both increase the physical gripping power of the surface very considerably; an increase of more than ten times has been observed. Acid washes also increase the adhesion. Electrodeposited tin does not increase the physical grip, but some form of physico-chemical bonding may occur between tin and a suitable paint. R. A. R.

Surface Preparation and Film Thickness. H. L. Bottemiller. (Paint, Oil and Chemical Review, 1947, vol. 110, No. 10, pp. 14–15, 36–37, 40: Railway Engineering Abstracts, 1948, vol. 3, May, p. 138). It is concluded from marine exposure tests on racks that surface preparation is a greater factor in film breakdown than the type of priming paint used (*e.g.*, red lead in oil, red lead in an alkyd or zinc chromate primer). Thus, various paint systems on sand-blasted panels remained in excellent condition whereas those on wire-brushed panels rusted after only 27 days' exposure. A linseed oil wash applied to rusty steel panels wetted the rusty areas and sealed the pores, enabling more highly developed media (*e.g.*, alkyd type) to be used. This treatment is better than phosphoric acid or phosphoric acid/dichromate dips. From a number of tests on ships, it is concluded that protection may be achieved by a paint system at least 5–6 mils thick, *e.g.*, even by several coats of a paint giving a relatively porous film.

Stainless Steel Paint Offers Corrosion Resistance, Hardness and Attractive Surface. G. Black. (Materials and Methods, 1948, vol. 27, Apr., pp. 86–87). The paint consists of 18/8 stainless steel powder, and is supplied as a flake, or in paste form with 14% of Varsol and 1% of stearic acid. Almost any clear lacquer is suitable as a vehicle. Extensive tests are now being carried out to determine its corrosion- and wear-resistance.—M. A. V.

Protective Coverings for Marine Applications. I, II. R. Hammond. (Paint Manufacture, 1948, vol. 18, pp. 79–83, 129–131: Chemical Abstracts, 1948, vol. 42, June 20, col. 4368). This is a review of the present position of the provision of adequate protection for ship's hulls and marine structures against corrosive attack.

Marine Corrosion and Fouling. H. W. Rudd. (Paint Manufacture, 1946, vol. 16, pp. 347–352, 391–397, 431–434: British Abstracts, BII, 1948, Mar., col. 117). A survey is given, covering the historical development of marine anti-corrosive and anti-fouling compositions, and the formulation of paints based mainly on copper and mercury poisons. The mechanism of anti-fouling action is discussed.

POWDER METALLURGY

Time and Temperature Effects in the Sintering of Iron Powders. H. Bernstorff. (Metal Treatment, 1948, vol. 54, Summer Issue, pp. 85–89). Experimental studies are described of the sintering of 'DPG-Schleuder' iron powder, which is made by the disintegration and water quenching of a stream of molten metal. This, as made, bears a film of iron oxide which is reduced by hydrogen at 950° C; in this state, the particles are not in a very reactive state, while it has also been found that grain growth, essential for sintering, only takes place at temperatures higher than those required for more reactive powders such as the products of the Hametag process. By means of tensile tests on flat bars made from two fractions of the powder, fine and coarse, pressed at 6 tons/sq.cm. and sintered for 2, 4, 6, 8, and 10 hr in purified hydrogen at 850°, 1100°, 1150°, and 1300° C, it is found that there is no decline in strength between specimens sintered at 800° C and those sintered at 1000° C, the tensile strength and elongation rising with temperature in all cases, though, in the case of lower temperatures only, tending to show minima after 4 hr sintering. This latter effect is considered to be due to a transition from one reaction mechanism to another, an effect concealed at higher temperatures.—J. P. S.

Method of Measuring Lateral Pressure in the Moulding of Metal-Ceramic Objects. V. N. Goncharova. (Zavodskaya Laboratoriya, 1948, vol. 14, May, pp. 575–578). [In Russian]. A description is given of experiments carried out with a view to improving the design of moulds for use in powder metallurgy. In these experiments the pressure on the base of the moulds was followed with the aid of a dynamometer, while the lateral deformation of the mould was measured tensometrically. The relation between pressure and deformation for the steel mould used being known, the lateral pressure in the mould was readily found from the tensometer readings, its value being about 0·38 of the value of the direct pressure. Mould design is discussed and the use of those formulæ applicable to the design of thick-walled cylinders is stated to be satisfactory for diameter ratios $\leqslant 0{\cdot}7$.—S. K.

Cemented Carbides. E. M. Trent. (British Science News, 1948, vol. 1, No. 10, pp. 14–17). The development of tungsten carbide and its manufacture and properties are discussed. R. A. R.

The Theory and Behaviour of Compressed Powders. C. Torre. (Berg- und Hüttenmännische Monatshefte der Montanistischen Hochschule in Leoben, 1948, vol. 93, Apr.–May, pp. 62–67). The theory of plasticity is applied to the study of the relationship between pressure applied in powder metallurgy and the porosity of the products.—R. A. R.

Turbimetric Particle Size Analysis. J. R. Musgrave and H. R. Harner. (Brochure of the Eagle-Picher Research Laboratories, 1947: [Abstract] Bulletin of the British Non-Ferrous Metals Research Association, 1948, July, p. 226). Methods of particle analysis are described with special reference to the development of the turbimetric methods. Detailed instructions, auxiliary information and a bibliography are given. A useful table of specific gravities of various powdered metals and their compounds is included.

PROPERTIES AND TESTS

Mechanical Properties of Iron—New Conception of the Effects of Small Amounts of Carbon. (Iron and Coal Trades Review, 1948, vol. 157, July 23, pp. 199–200). These notes on a lecture by A. H. Cottrell to the British Iron and Steel Research Association were prepared by M. W. Thring. G. I. Taylor's conception of "dislocations" in the lattice and its further development by Burgers are discussed. Cottrell's new conception is that in each atomic plane crossed by a dislocation a dissolved carbon atom is attracted to, and moves into, the dislocation, and that it then requires a definite shear to separate the dislocation from the carbon atom so that the dislocation can move freely. Since the shear required to remove any dislocation from its associated carbon atoms will in every case be essentially the same, a sharp yield point for the whole of the crystal is implied. Immediately after overstraining, a number of dislocations remain freed from their attendant carbon atoms, and hence there is no yield point. In the course of time, however, the carbon atoms once again diffuse to the dislocations and anchor them, and the yield point reappears. This is verified by the fact that the rate of reappearance of the yield point has been shown by Nabarro to be the same function of temperature as is the diffusion rate of carbon in iron. Calculation shows that the amount of carbon needed to anchor all the dislocations, even in a heavily cold-worked material, is very small so that a simple picture of the importance of carbon atoms on the strength of steel is thus obtained. The reason why a dislocation attracts the atom to it is explained.—R. A. R.

Notes on the Problem of the Toughness of Metallic Materials. A. Legat. (Berg- und Hüttenmännische Monatshefte der Montanistischen Hochschule in Leoben, 1948, vol. 93, June, pp. 92–99). The properties and characteristics of metals which affect their toughness and the change from tough to brittle are discussed. The magnitudes of the resistance to slip and the fracture strength as used in testing do not adequately represent the cohesion. The factors which really govern the toughness are natural notches in the material and changes in them caused by thermal stresses. In the lower temperature range fracture occurs without thermal changes, whilst in the range of higher temperature the notch conditions are changed by thermal stresses in a manner which markedly affects the strength properties.—R. A. R.

The Principles and Uses of Simulated Service Testing. L. L. Wyman. (Materials and Methods, 1948, vol. 27, June, pp. 63–67). The usefulness of tests which simulate service conditions is discussed and examples are given of the equipment required for performing such tests on large and small components.—R. A. R.

Ductility and Elasticity of White and Gray Irons. R. A. Flinn and H. J. Chapin. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 141–153). *See* Journ. I. and S.I., 1947, vol. 155, Jan., p. 156.

On the Improvement in the Elastic Properties of Ferritic Alloys with 25% Chromium by Melting under Vacuum. J. Hochmann. (Comptes Rendus, 1948, vol. 226, June 28, pp. 2150–2151). A 25% chromium ferritic alloy was prepared by melting Swedish iron and super-refined ferrochromium in a high-frequency furnace. Test specimens were melted *in vacuo* at 1600° for 20 min and then cooled *in vacuo*; the specimens were forged between 600° and 800°. Chemical compositions and elastic properties before and after remelting are compared and the improvement in elastic properties is noted. Remelting *in vacuo* is shown to have caused considerable decarburization, deoxidation, and denitriding.—J. C. R.

100 lb. Tensile and Compression Tester. (Instruments, 1947, vol. 20, Nov., p. 1034).

Perforated Cover Plates for Steel Columns: Summary of Compressive Properties. A. H. Stang and M. Greenspan. (Journal of Research of the National Bureau of Standards, 1948, vol. 40, May, pp. 347–359). Eighty-eight steel perforated cover-plate columns have been tested in the elastic range. The experimental axial rigidity under compressive load of the uniform perforated lengths has been compared with theoretical values. The agreement in general was very good. The distribution of stress on the edge of the perforation of these columns was also measured. The maximum values of stress concentration found experimentally have been compared with theoretical values obtained for a single hole in a large plate. These experimental values also, in general, agreed with the theoretical values. The values of the average stress on the net area for the compressive tests to destruction of twenty-eight perforated plate columns were in nearly all cases greater than the maximum stress at failure for columns of the same size having solid plates.

Impact Resistance of Case-Hardened Gear Teeth. V. Košelev and O. Puchner. (Strojnický Obzor, 1947, No. 2, pp. 27–30; No. 6, pp. 146–153). [In Czech]. A series of tests has been carried out in the laboratories of the Skoda Works to obtain information on the influence of the base material, the quality and thickness of the case-hardened layer, the heat-treatment, and also that of grinding-off the case-hardened layer from the front part of the tooth, on the properties of gear teeth. The tests were carried out on specially prepared specimens, 20 × 20 × 60 mm, recessed at both ends to a depth of 7·5 mm to form two strips each 6 mm wide to represent the teeth to be tested. The bottoms were rounded off with a radius of 0·9 mm to correspond to practical conditions at a modulus of 3·5. These specimens were specially designed to facilitate reliable fixing in the testing machine, thus eliminating a possible source of error in measurement.

The tests were limited to factors which were known, or considered very likely, to have a decisive influence on the strength of the teeth. Even so, it was necessary to prepare 216 specimens. The specimens were of three steels with the following compositions:

	C, %	Mn, %	Si, %	P, %	S, %	Cr, %	Ni, %
A	... 0·15	0·34	0·19	0·37	0·022	0·15	0·08
B	... 0·13	0·92	0·21	0·022	0·024	0·87	traces
C	... 0·24	1·24	0·20	0·026	0·022	1·35	0·13

The following heat-treatments were applied: (1) Tempering above Ac_1 of the case-hardened layer but below Ac_3 of the core material; (2) standard double tempering, once above Ac_3 of the core and a second time below Ac_1; and (3) tempering only once, above Ac_3 of the core. Most of them were quenched in oil, but water was also used. A series of specimens was quenched in a bath of molten salt at 140–200° C. The impact tests were carried out with a standard Izod machine. After the teeth of the specimens had been broken off, the structures and hardnesses of the core and hardened layer were determined, and the surface of the break was examined. The following conclusions were arrived at: The case-hardened layer should be as thin as possible, a depth of 10% of the tooth thickness being about the optimum value. For steel of very high strength this layer should be made thinner still. Removal of the hardened layer on the front of the teeth increases the impact resistance of the tooth considerably, on the average by about 30%. Tempering in salt baths did not influence the impact resistance. The optimum tempering temperature for carbon steels is above Ac_3 of the core, whilst tempering from temperatures above Ac_1 (below Ac_3 of the core gives far lower impact values. For alloy steels the test results revealed no appreciable difference between the values obtained for single and double tempering at temperatures above Ac_3. No relevant information was obtained on the influence of free carbides and carbide network structures; in very thick case-hardened layers their influence is negligible.—E. G.

A Notch-Impact Test According to Schnadt. J. A. Haringx. (Ingenieur, 1946, vol. 58, pp. MK 15–17: Philips Research Report, 1947, vol. 2, Oct., p. 400). A new type of notch-impact bar has been introduced by Schnadt. With this bar the bending pressure does not act upon the material itself but on a hardened steel pin. Since the centre line of this pin functions more or less as the axis of rotation, and the material itself is thus entirely subjected to a tensile load, this is really a sort of impact-tensile test. The greatest advantage lies in the fact that every test bar breaks, even if no other notch is made in it. This makes it possible, with the same cross section of fracture (3 × 10 mm), to make several notches with very different radii of curvature. Consequently a series of widely divergent stress conditions can be treated.

The Application of the Conical Impression to the Study of the Influence of Speed on Resistance to Deformation of Metals. F. F. Vitman, N. N. Davidenkov, N. A. Alatin, and B. S. Ioffe. (Zavodskaya Laboratoriya, 1948, vol. 14, May, pp. 579–594). [In Russian]. A critical review of some possible methods of measuring the influence of speed of deformation on resistance to deformation is followed by a detailed development of a procedure for this determination, based on the study of the impression made on the specimen by a conical striker. First, the field of deformation produced by the impinging cone is considered, the surface of the impression being split into a series of bands sufficiently narrow for the normal stress in a given band to be considered constant; and the ratio of the speed of penetration of the cone to the radius of the impression (which is closely related to hardness) is chosen as the index of the speed of deformation. Next, the real significance of instantaneous hardness is discussed, and the relation between the results of static and dynamic determinations of this quantity is considered. Equations are then deduced for the calculation of real instantaneous hardness; these take into account the fact that the ideal cone, *i.e.*, with the apex a geometrical point, does not exist in practice. The integration of these equations is considered, and the values of some frequently used functions are plotted against values of one of the parameters. Finally, the problems of the exact determination of the energy used up in the penetration of the cone on impact and of the measurements of yield-point and the Ludwig hardness are dealt with. The experimental arrangement suggested, in which cone and specimen are suspended in such a way that they can swing with their axes horizontal, is examined, the effects of the relative masses of these two bodies and of the speed of impact being discussed. Experiments have shown that the above method is suitable for both high and low speeds of penetration by the cone.—S. K.

A New Method for the Determination of Plasticity. Yu. M. Chizhikov. (Zavodskaya Laboratoriya, 1948, vol. 14, May, pp. 608–613). [In Russian]. Details are given of a method for measuring plasticity, which is suitable for both experimental and control purposes. The specimen of square section (length of side 35–40 mm) 200–250 mm long, prepared by mechanical working or by casting in a special detachable mould, is passed at a speed of up to 6 m/sec, or greater, through a roll designed to give a reduction that increases progressively along the length of the specimen up to a maximum value of 75% or even greater. The minimum degree of reduction at which discontinuities make their appearance in the surface of the specimen is taken as the index of plasticity. For greater convenience, scales, calibrated for the roll passes adopted, can be constructed and photographed alongside the specimen; examples of these photographs are reproduced. S. K.

Theory of Plastic Flow *versus* Theory of Plastic Deformation. W. Prager. (Society of Rheology: Journal of Applied Physics, 1948, vol. 19, June, pp. 540–543). Typical theories of plastic flow and plastic deformation are discussed, and the concept of neutral change of stress is introduced. A neutral change of stress can be considered as a limiting case of either loading or unloading. It therefore seems reasonable to demand that the stress-strain relations for both loading and unloading should predict the same change of strain when applied to a neutral change of stress. It is shown that this condition is satisfied by the theories of plastic flow, but not by the theories of plastic deformation.

The Comparison of Flow and Relaxation. P. Laurent and M. Eudier. (Comptes Rendus, 1948, vol. 227, July 26, pp. 259–261). In a recently made comparison of flow and relaxation based on Bolzmann's principle of superposition, a formula was used which the present authors consider unsatisfactory because it implied that for a constant time the deformation was proportional to the load applied. The authors propose an alternative formula. When this was applied to values for an aluminium–copper alloy with 9·7% of copper, superposition of the experimental curves occurred only with loads below the elastic limit and short times (less than 10 hr). The authors describe briefly four other methods of comparison, one purely empirical, and the results produced; the empirical method gives the most satisfactory results.—A. E. C.

Application of Dynamic Similarity to Metal Structures with Elastic and Plastic Flow. M. W. Thring. (Nature, 1948, vol. 162, July 31, pp. 193–194). The author shows that the attempt to obtain dynamic similarity for the flow of a metal structure produces two dimensionless criteria, one applicable where momentum and elasticity are the dominant factors, and one where elasticity and plasticity are dominant. In the first case, in for example impact testing, or the elastic oscillations of a clamped bar, the inertia of the material itself and the elastic forces are the important factors and the author is able to show that the usual similarity condition applies, that velocity must be kept constant, that is, that the time scale must be shortened in proportion to the reduction in linear dimensions. In the second case, where plastic or viscous forces, as well as elastic forces are important, but inertia can be neglected, it becomes essential to use the same material for the model as for the original, and the similarity condition is now that the time scale shall be the same as the original. It follows that where both inertial and rate-dependent plastic forces are important, dynamic similarity cannot be achieved; particular cases of this are brittle fracture and fatigue, impact testing and, in some cases, fibrous fracture. However, similarity can be obtained in cases of creep, internal damping, rate-of-loading effects, elastic after-effects and plastic flow in the work-hardening range; in these latter cases external impact forces may be included, if they are scaled to the square of the ratio of dimensions. In studying the effect of self-oscillations upon permanent set, the model must be externally loaded to give the same period of oscillation as the original.

The author concludes that this simple similarity criterion makes possible useful laboratory study of the rate-of-loading and damping effects in wire ropes, ship or car hulls, and girders.—J. P. S.

Developments in High Speed Rotating Disk Research at M.I.T. C. W. MacGregor and W. D. Tierney. (Welding Journal, 1948, vol. 27, June, pp. 303-s–309-s). The Massachusetts Institute of Technology has installed a 'whirl pit' in which steel discs, plain and welded, are rotated in a partial vacuum at speeds up to 12,000 r.p.m. by a steam turbine. This method of studying plastic flow and fracture properties has great advantages over hydraulic bursting tests, in that the ratio of the radial and tangential stresses remains nearly constant, up to fracture. The results of various pilot tests are presented.—J. P. S.

Influence of Size and the Stress System on the Flow Stress and Fracture Stress of Metals. D. J. McAdam, jun. G. W. Geil, D. H. Woodard, and W. D. Jenkins. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2373 : Metals Technology, 1948, vol. 15, June). The purpose of the investigation was to determine the influence of a wide range of sizes of specimen on the flow stress and fracture stress of both notched and unnotched cylindrical specimens. The statistical theory of fracture was found not to be applicable to the fracture of metals after even slight plastic deformation. The test data showed conclusively that the increase in fracture stress with increase in the sharpness of the notch is due to the increase in the ratio of transverse to longitudinal tensile stress, and not to a size effect.—R. A. R.

Mathematical Treatment Yields Explanation of Brittle Fracture. F. K. T. van Iterson. (Proceedings of the Koninklijke Nederlandsche Akademie van Wetenschappen, 1947, vol. 50, No. 3, Reprint). The distribution of stress in a steel beam and in a bar with hyperbolic longitudinal grooves in two opposite sides is analysed and formulæ are presented for calculating the three principal stresses. It is shown that the stresses in a rapidly cooled hot-rolled beam may be so great that, when loaded, the fracture stress may be reached before plastic flow begins, in which case brittle fracture will occur.

Influence of the Degree of Deformation on the Dependence of Stress upon Speed. L. Sokolov. (Journal of Technical Physics, U.S.S.R., 1948, vol. 18, Jan., pp. 93–97 : Applied Mechanics Review ,1948, vol. 1, Apr., pp. 109–110). Cylindrical specimens of lead, tin, aluminium, zinc, copper, nickel, ten kinds of steel, and brasses with different percentages of zinc were subjected to compression at speeds of 0·01 to 2000 mm/sec. From these experiments, described in an earlier paper (Journal of Technical Physics, 1946, No. 4, p. 437), the author concludes that for high-melting-point metals the speed coefficient decreases with increase of deformation at 20° C. and increases at high temperature, for low-melting-point metals the speed coefficient increases at 20° C and higher. From the diagram for copper at 900° C it is deduced that the relation between the plastic stress and the velocity is most conveniently expressed by a double logarithmic relation, as indicated by Rejto and others.

Calculation of Pressure Vessels in Connection with Investigation of the Occurrence of Brittle Fractures. W. P. Kerkhof. (Ingenieur, The Hague, 1948, vol. 60, Feb. 20, pp. MK 13–21 : Applied Mechanics Review, 1948, vol. 1, Apr., p. 109). Below a temperature of 350° C failure by fatigue has to be taken into account, and for this the author recommends the von Nises-Hencky criterion, as modified by Roš for the welds. For higher temperatures, the allowable stress has to be based on the allowable strain and transcrystalline and intercrystalline fracture. If Bailey's theory of creep is applied and if it is assumed that transcrystalline fracture occurs when the strain in any direction surpasses a certain amount, it appears that, as far as the strain and transcrystalline fracture is concerned, the same modified von Mises-Hencky criterion may be applied. For intercrystalline fracture the author assumes the 'amount of strain energy' to be the limiting factor. According to his formulæ he means by the amount of strain energy the strain energy due to the change of volume.

Anelastic Properties of Iron. T'ing-Sui Kê. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2370 : Metals Technology, 1948, vol. 15, June). Internal friction measurements on torsion wire were made on specimens of very pure iron wire (C 0·005%, O_2 0·040%, N_2 0·004%). The 'free decay' method was used starting with cold-worked wire and then on specimens annealed at temperatures in the 50–600° C. range. Measurements were made after each anneal from room temperature up to the annealing temperature ; the frequency of vibration in each case was of the order of 1 cycle/sec. When the internal friction was plotted against temperature three peaks were found at 20°, 225°, and 490° C. respectively.

The peak at 20° C. is caused by the anelasticity associated with the stress-induced preferential distribution of nitrogen atoms among the various interstitial positions in the solid solution of iron. The heat of activation associated with this relaxation for the case of nitrogen was found to be 20,000 cal/mole.

The 225° C. peak is caused by the stress-induced diffusion of nitrogen atoms within some peculiar type of stress regions created in the specimen after cold work. Relaxation experiments indicated that the heat of activation for this diffusion is 32,000 cal/mol, and the diffusion distance is of the order of a few atomic diameters.

The 490° C peak is caused by the grain-boundary relaxation in α-iron, and is similar to the grain-boundary relaxation previously observed in aluminium, magnesium, and α-brass. The heat of activation associated with this relaxation is 85,000 cal/mol.—R. A. R.

What Kind of Information Does Brittle Coating Give? A. J. Durelli. (Product Engineering, 1948, vol. 19, June, pp. 86–91 ; July, pp. 133–136). Examples are shown of the patterns obtained by (*a*) stressing a brittle coating on an eyebar loaded in tension, and (*b*) the isoentatics, or lines obtained by joining the ends of the cracks at each increment of load. Formulæ for determining stress in different zones of brittle-coating patterns with more than the usual accuracy are given in Part I, and in Part II these are applied to determine the stress distribution in a ring under compression. R. A. R.

Fatigue Tests of Spot Welds : Improvement of Their Endurance Limit by Hydrostatic Pressure. G. Welter. (Welding Journal, 1948, vol. 27, June, pp. 285-s–298-s). An 'amelioration treatment' for spot welds in aluminium alloy, stainless steel, and mild steel consists of applying high pressure to the weld spot by means of steel plungers and preventing sideways flow so that practically full hydrostatic pressures are attained. Fatigue tests indicate a considerable increase in the endurance limit.—J. P. S.

Fatigue Tests of Welding Elbows and Comparable Double-Miter Bends. A. R. C. Markl. (Welding Journal, 1948, vol. 27, June, pp. 310-s–320-s). Fatigue tests on elbows and double mitre-bends welded into 4-in pipe indicate that, for an identical number of cycles to failure, a welding elbow of long radius (1½ times nominal diameter) can be stressed to 20% higher in bending in the plane of the elbow, and 70% higher transverse to the plane, than a double-mitre bend of similar proportions.—J. P. S.

New Wire Fatigue Testing Method. F. A. Votta. (Iron Age, 1948, vol. 162, Aug. 12, pp. 78–81). A new instrument is described for the application of rotating-beam fatigue tests to wire. One end of the specimen is held in a rotating chuck, the wire is bent into a semi-ellipse and the free end inserted in an adjustable bush in which it is free to rotate. Simple supports keep the loop horizontal and prevent vibration. The chuck rotates at 3600 r.p.m., and complete fatigue tests on wire up to 0·03 in. in dia. can be carried out in a very few days.—J. P. S.

The Significance of the "Number of Reversals" in the Estimation of Sheet Metal. J. H. Palm. (Metalen, 1948, vol. 2, June, pp. 210–221). [In Dutch]. A description is given of a simple mechanical device with which alternating bend tests can be made by hand on small sheet metal specimens. Its usefulness is compared with that of the Erichsen test. R. A. R.

Fatigue Tests on Crankshaft Steels. Part I—The Effect of Nitriding on the Fatigue Properties of a Chromium–Molybdenum Steel. Part II—Tests on Nickel–Chromium–Molybdenum and Chromium–Molybdenum–Vanadium Steels. P. H. Frith. (Journal of The Iron and Steel Institute, 1948, vol. 159, Aug., pp. 385–409).

Effect of Heat Treatment on the Endurance Limit of Alloyed Gray Cast Iron. T. E. Eagen. (Transactions of the

American Foundrymen's Association, 1946, vol. 54, pp. 230–240). *See* Journ. I. and S.I., 1946, No. I, p. 68A.

X-Ray Methods of Determining Surface Stresses in Metals. H. Kohsok. (Publications de l'Institut de la Recherche Scientifique, Tettnang, 1947, No. 2, Oct., pp. 28–41 : [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 3/4, p. 588).

On the Relation between Deformation and Recrystallisation Texture of Nickel-Iron with Cubic Orientation. J. F. H. Custers. (Physica, 1947, vol. 13, Mar., pp. 97–116).

Researches on the Anisotropy of Metals and Alloys. G. Welter. (Revue Trimestrielle Canadienne, 1947, vol. 33, No. 129, pp. 15–47 : [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 7, p. 1291). A review is presented of the anisotropy of metals both stress-free and when subject to static or dynamic stresses. Experimental results are discussed.

Can You Use Lower Priced Alloy Steels? A. S. Jameson. (Steel, 1948, vol. 122, June 14, pp. 88–92, 106). The hardenability and working properties of some of the more economical alloy steels are discussed from the point of view of using them as substitutes for more expensive steels.—M. A. V.

A New Hardness Tester of Czechoslovak Design. J. Dobrý. (Hutnické Listy, 1947, vol. I, No. 8, pp. 177–179). [In Czech]. The Poldi Works developed a light, portable hardness tester based on the Vickers principle, the size of which is about that of a standard table-model microscope. The impression is obtained by a spring-loaded diamond pyramid with a tip angle of 136°. The spring preloading is accurately calibrated and usually set to 30 kg. Other preloading values can be obtained by inserting distance pieces and one for a preloading value of 10 kg is supplied with the instrument. The spring is made of chromium–silicon steel. Extensive tests have been made to check the reliability of the spring. These tests consisted of subjecting them to dynamic compressive loads of 29 to 36 kg for about 10 million cycles at 20° C, and shorter tests, of about 80,000 pulses, between 0° C and −65° C. It was found that hardness readings obtained with instruments fitted with tested springs did not differ from readings obtained with instruments fitted with new springs. The impression-measuring device is swivel-mounted on the ocular of the microscope permitting measurement of both diagonals. After making an impression, the microscope is moved into position by a simple swivelling and lowering operation, no other adjustment being necessary to view the impression, thus confusion between impressions cannot arise. The imprint is highly illuminated from a short focal length and the accuracy of reading is very high. The hardness values are obtained from tables as with a Vickers instrument. Specimens up to 150 mm thick are tested on a supporting plate, for larger parts this plate is removed and the tester is placed directly on to the object. Tests carried out by thirty-five operators were satisfactory and the scatter of values obtained by the various operators was very slight.—E. G.

The Practical Application of Hardenability Specifications. H. B. Knowlton. (Iron Age, 1948, vol. 161, June 3, pp. 72–77, 158, 160). It is suggested that it will be possible to achieve better control over heat-treatment, and reduce the number of changes required in manufacture, when hardenability tests for as-quenched and as-tempered heats become common practice. At least 50 heats of steel should be studied to determine, even approximately, the maximum and minimum hardenability within any specific analysis range. The purchase of alloyed steels under controlled hardenability specifications is recommended. Correlation of minimum hardenability with physical properties and with percentage of martensite, hardenability bands, and the limitations of hardenability tests are considered.—J. H. B.

Hardness Testing of Soft Metals. T. H. Gray. (Iron Age, 1948, vol. 161, June 24, pp. 82–87, 94). The errors which may arise when determining the hardness of soft metals (*i.e.*, those with a hardness below 400 diamond pyramid) are pointed out, and difficulties in the conversion of one scale to another are discussed.—R. A. R.

A New Design of Microhardness Tester and Some Factors Affecting the Diamond Pyramid Hardness Number at Light Loads. R. F. Campbell, Q. Henderson, and M. R. Donleavy. (Transactions of American Society for Metals, 1948, vol. 40, pp. 954–982). A description is given of a new design of diamond-pyramid microhardness tester using loads in the 5–100 g range. In the 225–900 Vickers hardness range, with loads of 50 to 100 g, the measurements agree well with those using a standard Vickers machine at loads of 10 and 30 kg. At below 50 g the hardness number obtained with the new machine decreases with decreasing load. Tests on iron carbide indicated that plastic flow occurs during indentation.—R. A. R.

Production Hardness Testing. O. L. Mitchell. (Steel, 1948, vol. 122, May 3, pp. 104, 126). The Webster B hardness tester, used for aluminium alloy sheet, is a plier-like instrument, in which a spring-loaded penetrator indents the sheet and a dial gauge indicates depths of penetration.—J. P. S.

Methods and Instruments for Hardness Testing. A. M. White. (Steel, 1948, vol. 123, July 26, pp. 74–82). Well-known scratch, rebound, and penetration hardness testing machines are described.—J. P. S.

Strain Aging Criteria. G. Sachs. (Iron Age, 1948, vol. 161, May 13, pp. 78–82). The susceptibility of steels to strain-ageing has been determined by various methods such as the measurement of tensile properties, yield strength, elongation, etc., at various lengths of time after cold-working, and at various temperatures, by noting the reappearance of the yield point, and by impact tests. There is no agreement between the criteria established by these tests for classifying a steel as ageing or non-ageing, and it is not yet fully established that any commercial non-ageing steel has, in fact, been made.
J. P. S.

Special Cast Steels with High Resistance to Wear. A. Hencks and J. Birens. (Revue Technique Luxembourgeoise, 1948, vol. 40, July–Sept., pp. 126–147). The mechanism of wear and the factors, in steel and in the methods of working, conducing to wear are discussed. Alloying elements (such as chromium, manganese, nickel, silica, molybdenum, and tungsten) can be added to cast steels in order to improve their wear-resisting properties, and special treatment for hardening the surface layer, cementation, surface hardening by induction heating, or diffusion of special elements, nitriding, or covering the surface with a hard metal or carbide layer, will also improve these properties.—R. F. F.

The Wear of Steel Specimens Free to Bend Elastically. R. Walzel and R. Werner. (Berg- und Hüttenmännische Monatshefte der Montanistischen Hochschule in Leoben, 1948, vol. 93, Apr.–May, pp. 59–62). It had been noted that a rigid rail, *i.e.*, one of heavy section across closely spaced sleepers, suffered more wear under the same load than a lighter rail which could bend between sleepers placed at greater intervals. This paper describes an apparatus in which steel specimens 200 × 14 mm, 3·5, 5, and 6 mm thick, clamped at each end, were moved to and fro a distance of 110 mm under a loaded piece of high-speed steel 16 mm in dia. The 3·5 and 5-mm specimens bent under the load and the 6-mm specimens were regarded as rigid. The absolute wear decreased with decreasing thickness, and along each specimen there was less wear at the centre where the bending was greatest than at some distance on each side of the centre.
R. A. R.

Effect of Structure on the Boundary-Lubrication Behaviour of Cast Iron. J. Kluge, G. Bochmann, and L. Fiddecke. (Zeitschrift für Metallkunde, 1948, vol. 39, May, pp. 139–142). The influence of the graphite formation on the wear of cast iron in sliding friction with steel using different lubricants was studied using 3·77% carbon piston-ring cast-iron specimens with the graphite in the coarse, medium, and fine states. With the lubricants tested the wear was greatest with the fine graphite which was contrary to expectations from measurements of hardness and strength of the three irons. This is explained by the very strong adsorbtive bond between the lubricant and the material in the case of the fine structure.
R. A. R.

The Theory of the Galvanomagnetic and Thermomagnetic Effects in Metals. E. H. Sondheimer. (Proceedings of the Royal Society, Series A, 1948, vol. 193, July 21, pp. 484–512). The methods of a previous paper are used to discuss the effect of a magnetic field on the thermoelectric power of a metal containing two overlapping energy bands of normal form. Exact solutions of the transport equation are obtained for the three limiting cases of high temperatures, low temperatures, and very strong magnetic fields, and it is shown that the formulæ can be generalized to give approximate expressions for all temperatures and all fields. The magnetic change of the thermoelectric power is found to be small at very low

and high temperatures, and to pass through a maximum at intermediate temperatures.

The transverse galvano- and thermomagnetic effects are also considered, and the formulæ which hold for free electrons are generalized so as to be approximately valid for all temperatures. For free electrons, the Hall coefficient remains constant as the temperature decreases, the Righi-Leduc coefficient increases, and the Ettingshausen and Ettingshausen-Nernst coefficients decrease and change sign at very low temperatures. The corresponding formulæ for a metal containing two bands are also obtained, and are used to show that the theoretical predictions for free electrons cannot hold for real metals except in special cases. Finally, the two-band model is used to discuss the effect of the magnitude of the magnetic field on the coefficients of the transverse effects.

Simultaneous Measurement of Tensional and Electrical Resistance of Fine Wires. J. T. Norton and G. C. Kuczynski. (Instruments, 1948, vol. 21, Apr., p. 328).

Gas Calorimeter Tables. R. S. Jessup and E. R. Weaver. (United States National Bureau of Standards, 1948, Circular 464).

Variations in Volume of Steel after Tempering. E. Kaminsky and D. Katznelson. (Journal of Technical Physics, U.S.S.R., 1945, vol. 15, No. 3, pp. 182–192 [in Russian]: [Abstract] Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Feb., p. 23). Results are presented of measurements of specific volumes of hardened steels, with different carbon contents, after tempering. The diminution of the specific volume after tempering between 300° and 400° C is attributed to a transformation of the cementite.

Supersonic Pulses Probe Metals to Hunt Flaws, Check Thickness. H. C. Drake and E. W. Moore. (Aviation Week, 1948, vol. 48, Mar. 22, pp. 21–23 : [Abstract] PERA Bulletin, 1948, vol. 1, July, p. 534). This article describes the use of two Sperry high-frequency instruments, the Reflectoscope and the Reflectogage for detecting flaws in steel stock, and gauging blade thickness, respectively.

Ultrasonic Method for the Non-Destructive Testing of Materials. J. Bénard. (Technique des Sciences Aéronautiques, 1947, No. 3, pp. 179–182 : [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 5–6, p. 961).

Ultrasonic Examination of Metals. V. Parenti. (Antenna, 1947, vol. 19, Apr.–May, pp. 217–218). [In Italian].

Testing Welds with Supersonic Waves. B. Carlin. (Welding Journal, 1948, vol. 27, June, pp. 438–440). This describes applications of supersonic testing technique to the examination of welds : the quartz crystal unit acts both as transmitter and receiver.—J. P. S.

Ultrasonic Testing of Welds. G. A. Homès. (Arcos Review, Belgium, 1947, July, pp. 2539–2552 : [Abstract] Engineers' Digest (London) 1948, vol. 9, July, p. 244).

Magnetic Particle Inspection in Engineering. D. E. Roda. (Iron Age, 1948, vol. 162, Aug. 5, pp. 79–83 ; Aug. 12, pp. 82–89). Standard methods of magnetic inspection are described and a system for filing the records of inspection is outlined. The classification of these indications in the aircraft industry is described.—J. P. S.

Quantitative Determination of Magnetic Properties by Use of Cathode-Ray Oscilloscope. J. Zamsky. (Transactions of the American Institute of Electrical Engineers, 1947, vol. 66, pp. 783–787). The author describes a means of producing the core-loss loops of samples of magnetic strips on an oscilloscope screen and a method of obtaining the heat loss from the areas of these loops. The standard Epstein test for obtaining the core loss requires a correction for corner effects due to stacking of the laminations, whereas the method described overcomes this by utilizing only the centre portion of relatively few short strips of the test material.—R. E.

Hiperco—A Magnetic Alloy. J. K. Stanley and T. D. Yensen. (Transactions of the American Institute of Electrical Engineers, 1947, vol. 66, pp. 714–718). The magnetic and mechanical properties of Hiperco are described. It is an iron–cobalt alloy containing from 14·5% to 35·5% of cobalt with the addition of an alloying element such as chromium to improve its hot and cold workability and to increase its electrical resistance.—R. E.

Non-Destructive Test Methods. B. Carlin. (Product Engineering, 1948, vol. 19, July, pp. 129–132). Electrical, X-ray, ultrasonic, thermal, magnetic, fluorescent, and optical methods of testing materials are briefly surveyed with notes on their sensitivity and particular sphere of application. R. A. R.

The Effect of Temperature on X-Ray Back-Reflection Measurements. V. Hauk and E. Osswald. (Zeitschrift für Metallkunde, 1948, vol. 39, June, pp. 190–192). The effect of temperature on the accuracy of the determination of lattice constants is discussed and a simple formula relating the correlation factor to lattice constant, the coefficient of linear elongation and the temperature is given.—R. A. R.

Radiographic Practice at Ford's. D. Goodman. (Iron Age, 1948, vol. 162, July 22, pp. 90–94). The X-ray plant and technique used by the Ford Motor Co. at Dearborn, for inspection, process development, and applied physics research are described. A very large amount of routine X-ray examination is carried out on cast parts, and X-ray diffraction methods are in use for the study of stresses. J. P. S.

Radiography. J. Strebelle. (Prévention des Accidents et Contrôles Techniques, 1948, vol. 2, Aug., pp. 293–300). The principles, technique, and applications of radiography are described. Protection of operators against radiation is briefly discussed.—R. F. F.

Radiographic Control of Welded Repairs in Steel Castings. R. Halmshaw. (Institute of Physics : Welding, 1948, vol. 16, July, pp. 284–290). Radiographic techniques evolved for the examination and elimination of flaws in steel castings are described. The relative merits of X-rays and gamma rays for examining castings are considered.—R. A. R.

Electronic Comparators. (Machinery Lloyd, 1948, vol. 20, Apr. 10, pp. 104–110 : [Abstract] PERA Bulletin, 1948, vol. 1, July, p. 533). In this survey the operating principle of the electronic comparator is briefly explained and the commercial advantages and versatile capabilities of the instrument are demonstrated by various applications, including qualitative testing of bar materials, segregating gudgeon pins into three different grades of hardness, measuring the thickness of anodic coatings on jet-turbine blades followed by detection of any weak spot in the coating, checking the composition of rubber rings, measuring tube-bore eccentricity and wall thickness, and inspecting bearing balls and rollers.

Beta-Ray Thickness Gage for Sheet Steel. O. J. M. Smith. (Electronics, 1947, vol. 20, Oct., pp. 106–112 : [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 5–6, p. 728). The relationship between the intensity of rays transmitted by the material and their normal intensity enables its thickness to be measured irrespective of its permeability or conductivity. The intensity of the rays is measured by Geiger-Müller measuring tubes and integrated circuits. Radiostrontium is the source of the rays.

X-Ray Thickness Gauge for Hot-Strip Rolling Mills. C. W. Clapp and R. V. Pohl. (Electrical Engineering, 1948, vol. 67, May, pp. 441–444). A description is given of a thickness gauge for detecting changes in the thickness of hot steel strip as it is rolled. An X-ray tube emits two beams, a reference beam passing through a standard wedge on to a phosphorescent screen in front of a photoelectric detector, and a measuring beam passing through a measuring wedge and the steel strip to a second detector. By adjustment of the positions of the wedges the absorption of the beams can be balanced to suit the correct thickness of the strip ; when off-gauge material passes through the measuring beam the detector outputs are thrown out of balance and the difference is shown on an indicator—R. A. R.

Limits of Precision in the Determination of Lattice Parameters and Stresses by the Debye-Scherrer Method. H. Ekstein and S. Siegel. (National Advisory Committee for Aeronautics, 1947, Technical Note No. 1375, pp. 1–22 : Applied Mechanics Review, 1948, vol. 1, Apr., p. 102). The limits of precision in the determination of lattice parameters and stresses by the Debye-Scherrer method of X-ray diffraction are examined to determine their relation to the technique of measurement. The shape and breadth of a spectral line and those of the resulting Debye-Scherrer line are compared theoretically and experimentally after the curves have been matched by adjusting one point on the intensity scale. It is concluded that spectral-line width (in connection with film

grain) is the limiting factor for an increase in accuracy, in as much as the geometrical errors have been reduced greatly. A relative error (error in lattice spacing, divided by lattice spacing) of the order of magnitude of 2×10^{-15} was consequently found to be imposed as an experimentally determined uncertainty in the position of maximum intensity, equal to 0·1 to 0·3 of the line width. This spacing error corresponds to stress errors of 4380 and 810 lb/sq.in. for steel and zinc respectively. The effect of inhomogeneity of the sample is also discussed.

Determination of Internal Stresses. W. Soete. (Metalen, 1948, vol. 2, July, pp. 231–245). [In Dutch]. The X-ray and electrical resistance strain gauge methods of determining internal stresses are described and discussed, and a shorter description is given of the new method developed by J. Mathar and R. Vancrombrugge in which three resistance gauges are used to measure the changes in strain as a small hole is drilled into the plate under examination. (*See* "The Measurement of Residual Stress in Depth"—Journ. I. and S.I., 1948, vol. 159, July, p. 338).

Application of the Electronic Microscope to the Detection of Surface Defects. F. Bertein and J. Robillard. (Technique des Sciences Aéronautiques, 1947, vol. 45, pp. 274–277).

A Comparison of X-Ray and Gamma-Ray Methods for Testing Steel Castings. (Instrument Practice, 1948, vol. 2, May, pp. 285–286). In this statement by the Steel Castings Division of the British Iron and Steel Research Association X-ray and gamma-ray methods of testing steel castings are compared as to (*a*) cost, mobility, maintenance, and operation, (*b*) type of casting to be examined and type of flaw to be detected, and (*c*) cost of operation.—R. A. R.

The Application of Very Hard X-Rays for Penetrating Steel. (Stahl und Eisen, 1948, vol. 68, June 17, pp. 237–238). The development of the production of very hard X-rays is traced with particular reference to the principles and application of the betatron. This has led to the construction of 20-MeV equipment with which steel and heavy metals up to 500 mm thick can be examined with reasonable exposure times.—R. A. R.

The Detection of Cracks by X-Rays and Gamma Rays. C. Croxson. (Electronic Engineering, 1948, vol. 20, Apr., pp. 106–111 : Railway Engineering Abstracts, 1948, vol. 3, June, p. 153). The applications of X-ray and gamma-ray crack detection are reviewed. It is stated that the radiographic appearance is not a dependable guide in estimating the probable depth or width of a crack. Cracks of a width of 10 microns or less can be detected in steel up to about $\frac{1}{2}$ in. thick. On welds it is possible that small cracks will escape detection, but these do not appear to have any practical significance. The author states that gamma rays should not be considered as simple, equally efficient, substitutes for X-rays. Their chief value is that they can be used to give a general picture in positions which are inaccessible to X-ray apparatus.

Influence of Low Temperatures on the Mechanical Properties of 18 : 8 Chromium–Nickel Steel. D. J. McAdam, jun., G. W. Geil, and Frances J. Cromwell. (Journal of Research of the National Bureau of Standards, 1948, vol. 40, May, pp. 375–392). By means of tension tests of notched and unnotched specimens, an investigation has been made of the mechanical properties of various 18/8 chromium–nickel steels between room temperature and −188° C. One of the steels was ferritic ; the others were of the metastable austenitic type. Plastic deformation of the metastable austenitic alloys causes a phase change and thus hardens the alloy. The rapidity of this change increases with decrease in temperature. At low temperatures the hardening due to the phase change is so rapid that the load-extension curve sometimes has two maxima. For this reason six important strength indices are sometimes required to evaluate the mechanical properties.

Low Temperature Properties of Cast Steels. C. E. Sims and F. W. Boulger. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 357–375). Twenty-eight cast steels were subjected to impact tests at temperatures between 80° and −100° F. The data indicated that the notched-bar impact properties characteristic of a heat of steel were not reflected consistently by any other property measured. It therefore appears to be necessary to test each heat of steel when the low-temperature properties are important.—R. A. R.

The Properties of Metallic Materials at Low Temperatures. (Österreichischer Maschinenmarkt und Eisenhandel, 1948, vol. 3, Apr., pp. 73–76). Data on the impact resistance of ferrous and non-ferrous metals and alloys at temperatures of +20°, −20°, −60°, and −183° C are presented.—R. A. R.

The Creep of Metals. E. Orowan. (Journal of the West of Scotland Iron and Steel Institute, 1946–47, vol. 54, pp. 45–96). *See* Journ. I. and S.I., 1947, vol. 156, July, p. 442.

High Temperature Creep Testing. H. V. Kinsey. (Canadian Metals and Metallurgical Industries, 1948, vol. 11, June, pp. 19–22, 34). A detailed description is given of the new creep-testing equipment at the Department of Mines and Resources, Ottawa, with which tests can be made at up to 1150° C.—R. A. R.

A Combined Creep Machine and X-Ray Spectrometer. H. J. Tapsell, H. V. Pollard, and W. A. Wood. (Journal of Scientific Instruments, 1948, vol. 25, June, pp. 198–199). This machine has been constructed to examine the creep behaviour of metals, especially at elevated temperatures, at the same time as the X-ray structure is examined ; the specimen may oscillate about its axis by ± 5°, and the X-ray film in its own plane by ± 5° to spread X-ray reflection spots into a continuous band when desired.—J. P. S.

Comparative Creep Tests on Ring-Shaped and Cylindrical Specimens for Bending and Stretching, Respectively. I. A. Oding and S. I. Matveev. (Zavodskaya Laboratoriya, 1948, vol. 14, May, pp. 595–607). [In Russian]. An account is presented of the creep testing of ring-shaped and cylindrical specimens for bending and stretching respectively. The apparatus developed for these purposes, which enables the simultaneous testing of several specimens to be carried out, is described with special reference to the circuits used for close temperature control. The results obtained by the two methods are compared and figures obtained for three alloy steels at 550–650° C are given. Except for one anomalous case (stated to be due to fluctuation of temperature) the bend and tensile tests gave concordant results.—S. K.

A Summary of Heat Resistant Alloys from 1200° to 1800° F. N. J. Grant, A. F. Frederickson, and M. E. Taylor. (Iron Age, 1948, vol. 161, Mar. 18, pp. 73–78 ; Apr. 8, pp. 75–80 ; Apr. 15, pp. 84–93). Data on the composition and physical properties, especially creep, of 53 heat-resisting alloys, published in the last seven years by industry and government departments, are presented and reviewed.

Heat-Resisting Steels. L. F. Keeley. (Machinery Lloyd, 1948, vol. 20, Apr. 10, pp. 68–71 : [Abstract] PERA Bulletin, 1948, vol. 1, July, p. 546). Nine typical types of heat-resisting alloy steels are reviewed, showing the effects of their alloying constituents on their ability to withstand loads at high temperatures and to resist attack in hot corrosive atmospheres. Many applications of this class of material are listed but particular attention is paid to carburizing boxes and gas turbines. Welding is briefly mentioned and a number of casting hints are given. There is an explanation of the term "creep" and its influence on design.

High-Temperature Alloys. L. B. Pfeil. (Revue du Nickel, 1948, vol. 14, Jan.–Mar., pp. 1–8 : [Abstract] Bulletin of the British Non-Ferrous Metals Research Association, 1948, July, p. 220). The requirements of high-temperature alloys, compositions of chief alloys used and their applications in jet engines are discussed. There are 34 references.

High Temperature Alloys. A. Dunlop. (Metal Industry, 1948, vol. 72, May 28, pp. 437–439 ; June 4, pp. 457–459). The essential properties of high-temperature alloys, particularly for use in gas turbines and methods of evaluating them, are discussed. The Hatfield 'Time-Yield' method is suggested as suitable for reporting creep, and values are given for a plain carbon steel and a number of typical heat-resisting alloy steels and non-ferrous alloys at temperatures of 400–1000° C. The creep and fatigue properties of REX 78 and G18B are given in detail ; the creep properties of the former are compared with those of REX 337A. American and German developments are discussed.

Development of High Creep Strength Austenitic Steel for Gas Turbines. D. A. Oliver and G. T. Harris. (Journal of the West of Scotland Iron and Steel Institute, 1946–47, vol. 54, pp. 97–136). *See* Journ. I. and S.I., 1947, vol. 156, Aug., p. 587.

Graphitisation of Low-Carbon, Low Alloy Steel—An Appraisal of the Literature. G. V. Smith. (Welding Journal, 1948,

vol. 27, June, pp. 227-s–284-s). This is a survey of the investigations reported since graphitization in welded 0·5% molybdenum steel was first noted in 1943.—J. P. S.

Viscosity. A Critical Survey of the Viscometry of Molten Iron–Carbon Alloys. E. T. Linacre. (Iron and Steel, 1948, vol. 21, July, pp. 315–318; Aug., pp. 363–366). A critical survey is presented of past work on the viscometry of high-carbon (C 2%–4%) iron; it deals with the change of viscosity of molten cast iron with temperature while a fixed constitution is maintained. The temperature range considered is that above the liquidus, since below this, the formation of a suspension of crystals causes an effective increase in the viscosity which is too rapid for accurate measurement. The effect on the viscosity caused by varying the quantities of the usual impurities of plain iron–carbon alloys at a fixed temperature, is also covered by this review. In the first part the author deals with measurement of the viscosity of molten white cast iron and in the second with measurement of the viscosity of molten grey cast iron, and finally considers methods suitable for the viscometry of steels. A bibliography of 43 references is appended.—J. C. R.

The Relationship between Coldworking and Hydrogen Embrittlement. C. A. Zapffe and M. Eleanor Haslem. (Wire and Wire Products, 1948, vol. 23, June, pp. 475–478, 527–529). Using the slow bend test which the authors described in a previous paper (*see* Journ. I. and S.I., 1947, vol. 157, Sept. p. 149) on cleaned and hydrogen-treated wire of 17%-chromium 1%-carbon steel, the effect of cold work on the hydrogen embrittlement was investigated. When slip takes place within a crystal during cold work a certain looseness, or imperfection, rather than an ideal arrangement of atoms rolling on atoms, is developed. Hydrogen and cold work combine to open and develop the latent loose structure of annealed metal. Cold work increases the capacity of the metal for absorbing hydrogen, and, by exhausting a proportion of the available slip movements, it leaves the metal more liable to hydrogen embrittlement. Rough handling of coils of wire in the mill may cause sufficient cold work at local positions to make it very liable to embrittlement in subsequent pickling operations. Careful annealing removes the effects of cold work and makes the metal much more resistant to hydrogen embrittlement. Cold working a hydrogen-treated metal causes much of the hydrogen to escape. Other conditions being equal, embrittlement develops more rapidly with increasing pickling temperature.—R. A. R.

Sensitivity of Different Steels to Pickling Brittleness. C. A. Zapffe and M. Eleanor Haslem. (Wire and Wire Products, 1948, vol. 23, July, pp. 563–569, 609–612). The manner in which the amounts of alloying elements and carbon, and the heat-treatment affect the sensitivity of steel to pickling embrittlement was investigated. The conclusions are: (1) Annealed steel is least, and hardened steel most, susceptible, and cold work increases the susceptibility; (2) of the stainless steels, the thermally hardenable are the most susceptible; (3) susceptibility increases with increasing carbon; (4) annealed stainless steels 410 and 431 resist embrittlement even when cold drawn; (5) with the exception of steel 440-C the stainless steels are less susceptible to embrittlement in acid pickling than they are in cathodic pickling; (6) steel 440-C is damaged by 7% HCl slightly more than by 10% H_2SO_4; and (7) all the acids studied, except HNO_3, cause similar injury in equal pickling times; this was indicated by bend tests on 0·20% carbon steel and stainless steel 440-C.
R. A. R.

Evaluating Hydrogen Embrittlement in Acid Pickling. M. Rosenfeld. (Iron Age, 1948, vol. 161, June 17, pp. 82–87). The hydrogen embrittlement of 0·20% carbon steel in acid-pickling solutions was investigated. Pickling with 3·6*N* H_2SO_4, alone or with most inhibitors, at 175° F produces embrittlement not completely removable by a subsequent 10-min boil in water. Adding formaldehyde to 3·6*N* H_2SO_4 alone or with inhibitors, tested at 175° F makes it possible to remove all observable embrittlement by boiling for 10 min. Use of quinoline-formaldehyde or of *p*-toluidine-formaldehyde mixes in 4·8*N* HCl solutions at 77° F appears to prevent embrittlement so that subsequent boiling is unnecessary. A similar effect is obtained for these mixes in H_2SO_4 at 175° F, but inhibition of metal attack is not obtained in the sulphuric acid. Tensile fracture in the Universal testing machine provides a rapid means of recognizing embrittlement if the reduction of area is also measured. The depth of penetration of the embrittlement can be observed.—R. A. R.

Influence of Grain Size on Diffusion of Nitrogen. A. G. Andreeva, I. E. Kontorovich and A. A. Sovalova. (Journal of Technical Physics, U.S.S.R., 1947, vol. 17, Dec., pp. 1521–1526 [in Russian]: [Abstract]. Metals Review, 1948, vol. 21, June, p. 14). It is shown that diffusion of nitrogen into iron increases with grain size. The maximum depth of diffusion is observed after the critical degree of deformation and recrystallization takes place. Depending on grain size, the depth of the diffusion layer increases from 0·26 to 0·6 mm.

Hydrogen Attack on Carbon Steels. T. C. Evans. (Mechanical Engineering, 1948, vol. 70, May, pp. 414–416). Seamless tubing, lap-welded pipe, and butt-welded pipe made of low- to medium-carbon unalloyed steels and Toncan iron were subjected to the action of hydrogen at 350 lb/sq.in. at 310–340° C for periods up to six years. The sections that showed attack were of steels containing 0·10–0·35% of carbon. Toncan iron was unaffected after twenty months' exposure.
M. A. V.

Diffusion of Carbon in Austenite. M. E. Blanter. (Journal of Technical Physics (U.S.S.R.), 1947, vol. 17, Nov., pp. 1331–1340 [in Russian]: [Abstract] Metals Review, 1948, vol. 21, May, p. 12). A new method is given for the determination of the diffusion constant. A formula for the above diffusion as a function of carbon concentration and temperature is derived from a study of experimental data. This formula has a maximum error of 7·5% to 8%.

The Sorption of Gases on a Plane Surface of Two Stainless Iron–Chromium–Nickel Alloys at 20°, −78°, and −183°. M. H. Armbruster. (Journal of the American Chemical Society, 1948, vol. 70, May, pp. 1734–1742). The sorption of argon, neon, hydrogen, nitrogen, carbon monoxide, oxygen, and carbon dioxide on the surfaces of two 18/8 chromium–nickel steels was measured. The surfaces were degreased, degassed, reduced by hydrogen, and degassed again; experiments were carried out at −183°, −78°, and 20° C, at pressures up to 0·1 cm. Neon and hydrogen were not measurably sorbed. Argon was slightly sorbed at −183° C, and not removable by pumping. Nitrogen was more strongly sorbed, but the sorption was reversible. With oxygen at −183° C, about two monolayers were chemisorbed, and a fraction of a monolayer reversibly held. Carbon monoxide was the only gas physically adsorbed to the extent of a monolayer. It is concluded that the reversible sorption of carbon monoxide at −183° C is a reasonable criterion of surface areas of stainless alloys; nitrogen and argon are also satisfactory on mild steels.—M. A. V.

Improving Properties with Nickel Alloys. J. S. Vanick. (American Foundrymen's Association: Canadian Metals and Metallurgical Industries, 1948, vol. 11, May, pp. 14–18; June, pp. 14–18, 32–33). The first part of the paper deals with the effect of nickel on bronzes. In the second part a comprehensive account is given of the effect of nickel on the properties of iron and steel.—R. A. R.

Copper and the Steel Casting—An Alloy for Post-War Consideration. H. F. Taylor, H. F. Bishop, and R. C. Wayne. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 213–224). *See* Journ. I and S.I., 1946, No. II, p. 99A.

Carbon–Beryllium Steels. W. Aichholzer. (Berg- und Hüttenmännische Monatshafte der Montanistischen Hochschule in Leoben, 1948, vol. 93, June, pp. 100–114). A comprehensive investigation on the effect of additions of up to 1·5% of beryllium on the properties of 0·05–1·0% carbon steels is reported. The Ac_1 point rises slightly with increasing amounts of beryllium. From the point of view of the $\alpha \rightleftharpoons \gamma$ transformation, beryllium steels are classified into ferritic, semi-ferritic, and completely transformable steels, and the solution of the beryllium-bearing carbide with increasing temperature is indicated. In the unhardened state beryllium markedly increases the hardness, but with increasing carbon this increase in hardness diminishes. Tensile and impact test data showed that beryllium steels behaved similarly to other alloy steels, except with the greater additions of beryllium when the elongation, reduction of area, and impact values were lower. Beryllium improves the resistance to scaling. Steel with carbon 0·05% and beryllium 1·66% was rapidly attacked by HNO_3 and H_2SO_4, but was to some

extent resistant to dilute HCl. Adding up to 1% of beryllium to 0·9% carbon steel increased the coercivity and the remanence, but with more beryllium these values decreased.—R. A. R.

When and How to Use Gray Iron. T. E. Eagan. (Foundry, 1948, vol. 78, Aug., pp. 84–91). Data on the mechanical properties of grey cast iron are presented and other properties such as damping, machinability, corrosion and heat resistance, density, thermal conductivity and expansion, and specific heat are discussed. Comparisons are made with steel to show the particular applications for which cast iron is suitable. R. A. R.

Gray Iron Castings Section Sensitivity. H. C. Winte. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 436–443). *See* Journ. I. and S.I., 1947, vol. 156, July, p. 445.

Engineering Properties of Heat Treated Cast Irons. J. S. Vanick. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 460–464). *See* Journ. I. and S.I., 1945, No. II, p. 67A.

Nodular Cast Irons, Their Production and Properties. H. Morrogh and J. W. Grant. (Institute of British Foundrymen: Foundry Trade Journal, 1948, vol. 85, July 8, pp. 27–34; July 17, pp. 51–57; July 22, pp. 81–86; July 29, pp. 105–110). The method of producing nodular cast iron has already been described by Morrogh and Williams (*see* Journ. I. and S.I., 1948, vol. 158, Mar., pp. 306–322). In the present paper a detailed description is given of the mechanical properties of typical nodular irons and the commercial production of the iron is discussed.—R. A. R.

Nickel Cast Iron. A. E. Williams. (Engineering and Boiler House Review, 1948, vol. 63, June, pp. 175–177). The properties of the nickel cast irons are reviewed.—R. A. R.

Low Alloy High Tensile Steels. C. L. Altenburger. (S.A.E. Journal, 1948, vol. 56, July, pp. 21–23). The drawing properties of low-alloy high-tensile steels are discussed with notes on the differences in die and punch design for drawing these steels as compared with low-carbon steels.—R. A. R.

Nickel Alloy Steels. (Machinery, 1948, vol. 73, July 15, pp. 59–64). The properties and uses of nickel steels and nickel alloy steels such as nickel–chromium, nickel–molybdenum, and nickel–manganese steels, are summarized.—R. F. F.

Metallurgical Aspects in the Design of Rocket Motors. J. N. Nutt. (Journal of the American Rocket Society, 1948, No. 73, pp. 31–34: Chemical Abstracts, 1948, vol. 42, July 10, col. 4506). Problems of design are difficult owing to corrosive action of fuels and gases, and the extremes of high and low temperatures encountered in operation. The useful properties of the austenitic stainless steels of the 18/8 and other types are discussed. Data on the strengths of materials at the very high temperatures are scanty. Ceramic materials and porous metals offer good possibilities for rocket motors. Although the use of light material in rockets is desirable, aluminium and magnesium (which are the only comparable light metals available) are almost useless owing to their poor corrosion resistance and low melting points.

The Metallography and Properties of High Alloy Hot Work Steels. P. Payson and A. E. Nehrenberg. (American Iron and Steel Institute, May 26–27, 1948, Preprint). Data are presented on the microstructure and properties of four low-alloy steels (*a*, Ni 0·15%, Cr 5·21%, V 0·40% and Mo 1·38%; *b*, Ni 0·12%, Cr 4·97%, V 0·18%, W 1·31% and Mo 1·36%; *c*, Ni 0·12%, Cr 3·34%, V 0·26%, W 8·65%, and Mo 0·17%; *d*, Ni 0·10%, Cr 1·95%, V 0·31%, W 11·64%, and Mo 0·20%). All of these have residual carbides, but steels *c* and *d* contain more than *a* and *b*. Steels *c* and *d* are also much more resistant than the others to softening during long exposure at temperatures above 1000° F. Steels *a* and *b* are much more resistant in notch-impact tests at the lower testing temperatures. The hot-hardness, and hot-tensile, and thermal expansion properties are about the same for all four steels, whilst the tungsten steels have slightly higher thermal conductivity.—R. A. R.

French Alloy and Tool Steel Industry. (Iron Age, 1948, vol. 162, July 1, pp. 80–81). French alloy steel specifications, of which there are approximately 60, correspond closely to the grades in common use in the U.S.A., with the exception of air-hardening nickel–chromium and nickel–chromium–molybdenum steels with chromium over 4%, used for intricate parts, such as special gears, requiring high shock resistance, and a 1·5% carbon, 12% manganese steel used for crusher jaws. A list of 44 manufacturers is included.—J. P. S.

High Alloy Tool and Die Steels. J. Bronner. (Machinery Lloyd, 1948, vol. 20, Apr. 3, pp. 72–74: [Abstract] PERA Bulletin, 1948, vol. 1, July, p. 546). The author discusses the effects of alloying elements on tool steel, and describes the hardening processes and uses of various high-alloy types.

Characteristic Properties and Uses of Molybdenum Steels. H. U. Meyer. (Métallurgie, 1948, vol. 80, June, pp. 21–23, 25). After reviewing the relationship between the various mechanical properties of steels, the author examines the effect of molybdenum on hardenability, and shows that quite small additions of molybdenum appreciably increase the hardenability of structural steels and improve their physical properties; moreover, as molybdenum is not oxidized in the bath the degree of hardenability can be readily controlled. The influence of molybdenum is also beneficial in the elimination of temper-brittleness. The advantages of molybdenum in heat-resistant, high-speed, tool, and die steels are indicated. J. C. R.

Vanadium Data Sheet. Vanadium Tool Steels. Part I. T. W. Merrill. (Vancoram Review, 1948, vol. 5, No. 3, pp. 10–13).

Pre-Stressing of Springs. J. A. Pope. (Coil Spring Federation: Wire Industry, 1948, vol. 15, July, pp. 455–456). The results of static torsion tests on overstrained specimens of 0·63% carbon spring steel $\frac{3}{8}$ in. in dia. are discussed, and the effect of heating for 1 hr. at 250° C. after overstraining is pointed out. This low-temperature heat-treatment increased the limit of proportionality by 33%.—R. A. R.

Wire Forms. H. Chase. (Wire and Wire Products, 1948, vol. 23, Apr., pp. 303–305, 348–350; May, pp. 394–398, 438). The selection of materials for springs and other tempered wire forms is discussed, and the hardness, ultimate tensile strength, elastic limit, and modulus of elasticity of commonly used steels and non-ferrous alloys are tabulated. Rules for the design of wire forms are tabulated.—M. A. V.

CORROSION

The Corrosion of Steel. C. A. Lobry de Bruyn. (Verfkroniek, 1948, vol. 21, pp. 89–92: Chemical Abstracts, 1948, vol. 42, July 10, col. 4511). This is an address giving a survey of the different factors of importance in the corrosion process, illustrated by a scheme of anodic and cathodic effects of the electrochemical process.

The Corrosion of Metals. II. Controlling Factors in Corrosion Reactions. H. J. McDonald. (Illinois Technical Engineer, 1947, vol. 12, Mar., pp. 13–17, 56, 58: [Abstract] Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Feb., p. 42). The following points are covered in this article: Influence of polarization and overvoltage; anodic and cathodic polarization; inhibitors; protective coatings; electrolytic protection; stress-corrosion cracking; and corrosion-fatigue resistance.

Contribution to the Study of the Corrosion of Metals. M. Pourbaix. (Bulletin de la Société Royale Belge des Ingénieurs et des Industriels, 1948, Série A, No. 2, pp. 97–108). The author describes some experiments undertaken to determine the relationship between electrochemical thermodynamics and corrosion phenomena. The behaviour of iron in the following media was studied: in a non-oxidizing acid solution; in a non-oxidizing alkaline solution; when used as an electrolytic anode; in the presence of oxygen-bearing solutions; and in the presence of potassium chromate-bearing solutions. Finally he considers what industrial use can be made of results derived from the thermodynamic study of corrosion phenomena.—J. C. R.

Combating Corrosion of Iron and Steel. (Metallurgia, 1948, vol. 38, June, pp. 104–106). This paper constitutes a brief report on the scope and practical character of the work of the Corrosion Committee of the British Iron and Steel Research Association and its sub-committees.—R. A. R.

Corrosion Research Work Carried Out in Sweden during the War Years. Eva Palmaer. (Métaux, Corrosion, Usure, 1945, vol. 20, Nov., pp. 153–154).

Present Status of Knowledge on Stress Corrosion Cracking of Iron. H. H. Uhlig. (Record of Chemical Progress, 1947, vol. 8, Jan.–Apr., pp. 21–23: [Abstract] Corrosion, 1948, vol. 4, June, pp. 27–28). This is a condensed review of stress-corrosion cracking of steel. Stress-corrosion cracking of early

steam boilers now countered by welding of boilers is mentioned. Chemical reagents are concentrated nitrate solutions at boiling temperatures, concentrated nitric acid at room temperature, hot dilute nitric acid plus manganous chloride at 60–80° C (except 46% magnesium chloride at 125° C), nitrates in rain water (attacking bridge cables), hydrogen cyanide (active ingredient in compressed illuminating gas), and impurities in steel combined with environmental factors (nitrogen makes steels more susceptible to failure in alkalis and nitrates whilst low concentrations of phosphorus plus nitrogen and aluminium are good). A possible mechanism involves precipitation of a compound such as an iron nitride at the highly stressed region at base of cracks.

Stress Corrosion Cracking of High Chromium Steel. L. A. Glikman and V. A. Stepanov. (Boiler and Turbine Construction, U.S.S.R., 1947, Feb., pp. 19–21 [in Russian]: [Abstract] Corrosion, 1948, vol. 4, June, p. 34). Cases of the failure of bushings on the shafts of tubines are described. It is established by experiment that the failure of the above steel was caused by stress-corrosion cracking. A mechanism is proposed for the latter.

Metals in Service. P. M. Hess. (Iron and Steel Engineer, 1948, vol. 25, June, pp. 65–76). This article deals with the types of corrosion—stress corrosion, cavitation, electrolytic corrosion—encountered in hydroelectric installations. Sprayed zinc coatings will protect head gates where water is not passing rapidly across them, cathodic protection will prevent pitting due to electrolytic effects, while cavitation can be resisted by the application of stainless steel weld-metal.—J. P. S.

Climatic Effects on the Corrosion of Steel. J. Dearden. (Journal of The Iron and Steel Institute, 1948, vol. 159, July, pp. 241–246).

The Atmospheric Corrosion of Ferrous Metals and Its Prevention. J. C. Hudson. (Gas World, 1948, vol. 129, July 3, pp. 7-s–24-s). The atmospheric corrosion of iron and steel is closely connected with the relative humidity and the degree of pollution of the atmosphere; rates of corrosion in an industrial atmosphere may be five or more times higher than those in non-industrial districts. The advantages derived from the use of low-alloy steels and the use of paints and metallic coatings are described.—J. P. S.

On the Corrosion of Iron in Acid Atmospheres. H. Ziegler. (Berne, May, 1946, Thesis: [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 1–2, p. 250).

The Resistance of Phosphatized Steel to Weathering. G. Schikorr. (Metalloberfläche, 1947, vol. 1, July, pp. 188–190). Steel specimens phosphatized by long-time and short-time hot processes as well as by the cold process were treated with oil and subjected to atmospheric exposure tests for one year in Berlin. The loss of weight as compared with the same steel without phosphatizing was reduced from 250 to less than 10 g/sq.mm. per annum in the case of the first and third processes; the reduction was considerable but not so great with the second process. Galvanized coatings 4μ thick had about the same corrosion resistance as phosphatizing by the first and third processes. Tests in a sea-water apparatus gave similar results in about one-tenth of the time.—R. A. R.

How Atmospheric Nitrogen Encourages Galling and Fatigue Failures. H. Schottky and H. Hiltenkamp. (Steel, 1948, vol. 123, July 5, pp. 97, 110, 113, 114). Fretting corrosion is accompanied by the absorption of nitrogen from the atmosphere, leading to the formation of a brittle component, detectable microscopically and chemically. From this brittle surface, cracks starting under alternate stresses may become the starting point of fatigue failures.—J. P. S.

Some Case Histories of Corrosion Problems in Chemical Process Equipment. W. Z. Friend and F. L. LaQue. (Transactions of the American Institute of Chemical Engineers, 1946, vol. 42, pp. 849–862). Brief accounts are given of investigations of the corrosion of chemical plant so as to illustrate the methods of attacking different problems. The presence of dissolved silicates was found to be a powerful inhibitor of the corrosion of 5% nickel steel tubes in a black-liquor evaporator in a Kraft pulp mill.

For a pump handling 45% sulphuric acid solution at 250° F at an oil refinery the best alloy was found to be 14·5% silicon cast iron.

In the case of a 24-in cast-iron pipeline carrying sulphur dioxide from sulphur burners to coolers, the corrosion was due to the inner surface being at a temperature below the dew point of the sulphuric acid formed along with the sulphur dioxide. Corrosion was prevented by lagging the pipe, and the lagged pipe cooled the gases more effectively than the unlagged pipe because in the latter case the corrosion products on the inside offered the greater barrier to the flow of heat.—R. A. R.

Corrosion of Iron in Commercial Sulphuric Acid and Nitrosylsulphuric Acid. F. Perktold. (Angewandte Chemie, Section B, 1948, vol. 20, May–June, pp. 125–128). In view of the shortage of lead in Germany tests were made on wrought iron, cast iron, and a number of steels to see whether they could be used in place of lead in certain parts of a chamber-process sulphuric acid plant. Iron cannot be used in contact with warm or hot sulphuric acid. Cast iron is resistant to chamber-crystal solutions at all temperatures encountered, whilst steel and wrought iron may be in contact with them at below the passivation temperature for only very short periods. The attack is very much greater at medium than at high temperatures, and the chief danger with both lead and iron is acid condensation and stagnant acids.—R. A. R.

Corrosion of Metals by Hydrochloric Acid at High Temperatures. Kh. L. Tseytlin. (Zhurnal Prikladnoy Khimii, 1948, vol. 21, Jan., pp. 35–41: [Abstract] Bulletin of the British Non-Ferrous Metals Research Association, 1948, June, p. 180). Loss-in-weight tests are reported on mild steel, 26% chromium steel, cast iron, and copper in hydrogen chloride (wet and dry) at temperatures up to 500° C.

Influence of Ammonia and Hydrocyanic Acid on Corrosion of Steel by Town Gas. H. G. Pyke. (National Gas Bulletin, Australia, 1947, vol. 11, Sept.–Oct., pp. 20–22: Fuel Abstracts, 1948, vol. 3, May, pp. 38–39). The work described was carried out by the Australian Gas Light Co. As some observations made in the course of other investigations indicated that ammonia was of more consequence than hydrocyanic acid in the corrosion caused by town gas, the tests described were carried out. They confirmed these observations in so far as steel is concerned. The initial tests in 1938, were made in accordance with the usual practice with polished steel specimens, which were exposed to: (1) saturated town gas; (2) saturated town gas, with ammonia removed; (3) saturated town gas with hydrocyanic acid removed; and (4) saturated town gas, with both ammonia and hydrocyanic acid removed. The tests described indicate that in town gas containing 0·2% oxygen: (1) of the two impurities, ammonia and hydrocyanic acid, the former is by far the more deleterious from the point of view of the corrosivity of the gas; (2) the presence of ammonia exerts a powerful accelerating effect on the corrosion of steel by the gas; this effect increasing with rising concentration, at least up to 7 grains per 100 cu.ft.; and (3) hydrocyanic acid, up to 3 grains per 100 cu.ft., is a factor tending to the protection of steel rather than to its corrosion, the corrosion products formed when it is present being of the adherent protective type as compared with the loose, porous, corrosion-promoting type formed in its absence.

Fluorine Corrosion. W. R. Myers and W. B. DeLong. (Chemical Engineering Progress, 1948, vol. 44, May, pp. 359–362). The resistance of a variety of metals to fluorine at higher temperatures was determined experimentally. Carbon steels with silicon below 0·01% can be used up to 350° C, but stainless steels only up to 250° C; type 347 stainless (containing niobium) is quite unsatisfactory. The anodic corrosion of steel in $KHF_2.HF$ at 90° C shows a marked increase when the p.d. rises above 5 V.—M. A. V.

Gamma Ray Detection of Internal Corrosion. L. R. Keller. (Petroleum Engineer, 1947, vol. 18, Sept., pp. 211–214: [Abstract] Corrosion, 1948, vol. 4, July, p. 30). Detection of internal corrosion is facilitated by the use of the gamma-ray instrument. Commercially known as "Penetron," it operates by measuring secondary radiation from gamma rays that are directed into the metal being tested. An accuracy of $\pm$ 5% over its range of measurement, between 0 and 0·75 in thickness, is obtainable. Intensity of radiation is proportional to thickness of metal. An auxiliary method employing gamma-ray absorption is also discussed. This method is accurate within 3% and has a range between 0 and 0·625 in thickness. The instrument has been used successfully to locate and measure corrosion in refinery piping, storage tanks, and other process equipment. It is best suited for examination of

flat plates, pressure vessels, and pipes of large diameter.

The Application of Galvanic Elements for Determining Oxygen Dissolved in Water and as a Corrosion Indicator. F. Tödt. (Archiv für Metallkunde, 1947, vol. 1, Nov.–Dec., pp. 469–471). Current strength measurements using a suitable galvanic couple provide a convenient method of determining oxygen dissolved in water, and the method has many advantages over the chemical method of Winkler. The former method is discussed with fourteen references to the literature. It is of a kinetic character and is therefore suitable for following rapidly changing phenomena. It can also be applied for evaluating paints and other protective coatings and measuring rates of corrosion.—R. A. R.

The Resistance of Alloys to Corrosion during the Processing of Some Foods. J. F. Mason, jun. (Corrosion, 1948, vol. 4, July, pp. 305–320). Results of corrosion tests are given for various metals to show the effects of various food products on them. The metals tested included, Inconel, Monel, various stainless, chromium, and mild steels, cast iron, and some non-ferrous metals and alloys. Samples of all these metals were simultaneously subjected under actual service conditions to various fruit juices, food acids, vegetable and meat extracts, and other food products normally processed. The results are given for each food product as a corrosion rate for each metal in inches penetration per year.—R. F. F.

The Internal Corrosion of Cans. Final Report. D. Dickinson. (Annual Report of the Fruit and Vegetable Preservation Research Station, Campden, 1946, pp. 21–30). In order to assess the corrosivities of fruit juices, a number of aqueous fruit extracts were electrolysed between steel electrodes, and the relationships between applied potential, current density, and rate of hydrogen evolution determined. It was found that there was a good agreement between the practical behaviour of fruits in lacquered cans and the electrochemical properties of the extracts. Hot-rolled and cold-rolled steel could be used indiscriminately; but the end seam was found to be especially susceptible to anodic corrosion. Uniformity of composition of steel in the can is important in minimizing corrosion. Sugar in the fruit juices has no corroding effect.
M. A. V.

Chemical Surface Condition and Passivation of Mild Steels with Low Alloy Additions. E. Herzog. (Métaux, Corrosion, Usure, 1945, vol. 20, Oct., pp. 127–134). In this study of the passivation of mild steels the author first examines the influence of preliminary chemical treatment and notes in particular the passifying action of chromates. The influence of the composition of the steel and the action of nitric acid when small amounts of chromium and aluminium are present in the steel were investigated. When they are present together the rate of attack is far less rapid than when either is present alone. Finally an outline is given of the electrochemical properties of the passifying film.—J. C. R.

Relation between Welding and Corrosion of Stainless Steels. A. de Sy. (Revue de la Soudure, 1945, vol. 1, pp. 3–26: British Abstracts, 1948, BI, May, col. 206). A general review of the mechanism of corrosion of steels is followed by a discussion of the types of corrosion, both general and localized. The electrochemical theory of corrosion is applied to cases of two dissimilar metals, to heterogeneous metal, and to two parts of the same metal which are differentially aerated. Forty per cent of the annual steel production is estimated to be lost by corrosion, and the methods of combating the trouble are reviewed. Perfect homogeneity in commercial steels, which would help, is impracticable, but metals such as chromium, copper, and nickel may be added to passify the metal. Chromium makes steel inert to oxidizing agents, whilst nickel increases the resistance to reducing agents. Phase diagrams are given for iron–chromium alloys. The welding of resistant alloys lowers their resistance, particularly to intergranular and fissure corrosion. Attempts have been made to overcome the difficulty by using as the welding electrode a metal which is more noble than the material to be joined.

Effect of Composition on Low Carbon Austenitic Chromium–Nickel Stainless Steels. G. C. Kiefer and C. M. Sheridan. (American Iron and Steel Institute, May 26–27, 1948, Preprint). The corrosion resistance and mechanical properties of stainless steels containing less than 0·035% of carbon, and different amounts of chromium, nickel, and nitrogen were investigated. In the fully annealed state the low carbon content does not improve the corrosion resistance; neither carbon, nickel nor nitrogen influenced the corrosion rates in boiling HNO_3, or the resistance to H_2SO_4 and salt spray. Increasing the chromium improved the resistance to HNO_3 but did not improve the resistance to H_2SO_4 and salt spray. After 100 hr exposure in the sensitizing temperature range the effect of carbon and nitrogen is determined by the chromium content; when this is about 17·5% the carbon must be kept well below 0·03%. With increasing chromium up to 20·5%, the influence of carbon and nitrogen becomes less, *e.g.*, with carbon 0·037% and nitrogen 0·25% the corrosion resistance was not severely impaired. Immunity to intergranular attack after long periods at the sensitizing temperature was affected by the above elements in a similar manner; there was evidence that a high chromium/nickel ratio is beneficial.—R. A. R.

Passivation of Stainless Steel. F. H. Beck. (Ohio State University, Engineering Experiment Station News, 1947, vol. 19, No. 5, pp. 32–38: Chemical Abstracts, 1948, vol. 42, Apr. 20, col. 2560–2561). 18/8 stainless steel readily corroded in 10% sulphuric acid at 50° in the as-polished condition. If the disturbed surface layer due to polishing was removed by etching in 10% sulphuric acid and the specimen was then exposed to air for a short time, the metal was rendered passive. The theory was presented that passivation resulted because of a physically adsorbed layer of gas. Passive specimens subjected to a vacuum of 0·002 mm or less for 6 hr or more were active when immersed in 10% sulphuric acid freed from air at 50° or synthetic sea water similarly freed from air at 50°. Exposure to air rendered the specimens passive. Argon and helium containing small percentages of nitrogen were effective in passivating specimens which had been activated by vacuum treatment. Spectroscopically pure argon and helium gave erratic results. Electron-diffraction examination was made of specimens which had been given the following treatments: Abraded in air; heated in boiling sulphuric acid for 3 min; dipped in cold sulphuric acid; dipped in cold nitric-acetic acid mixture; boiled in distilled water; and heated in air at 300–800° F.

Diesel Engine Wear Laid to Sulfur-Formed Abrasives. L. D. Thompson, S. J. Backey, and E. L. Conn. (S.A.E. Journal, 1948, vol. 56, July, pp. 44–45, 61). Data are presented on the wear of Diesel-engine piston rings and cylinder liners after running on five fuel oils containing different amounts of sulphur. The authors' theory is that, in the combustion reaction, sulphur combines with hydrocarbon molecules to form a black abrasive product, and that this deposit causes most of the wear.—R. A. R.

Dezincification and Erosion Corrosion. M. G. Fontana. (Metal Progress, 1948, vol. 53, May, pp. 686–689). Selective leaching of one of the constituents of an alloy is not confined to brasses. Cobalt has been removed from Stellite by a waste sulphuric acid slurry containing solid ferrous sulphate. A similar slurry also caused erosion corrosion on an 18/8 stainless steel containing molybdenum when this steel was employed in centrifuge bowls; examples are also given of the impinging-ment corrosion at an elbow of steel S.A.E. 1020 (0·18–0·23% C; 0·30–0·50% Mn) and of a high-alloy stainless pump impeller. A special test unit has been constructed to study the problem.
J. P. S.

Experience in the Corrosion of Steel Tubes from Cold and Hot Water Systems and Boilers. W. M. Müller. (Archiv für Metallkunde, 1947, vol. 1, Nov.–Dec., pp. 480–487). This paper reviews investigations carried out on old steel tubes removed from hot and cold water systems and boilers. The corrosion phenomena studied are in five groups as follows: (1) Scaling and corrosion phenomena; (2) feedwater and the corrosion of boiler tubes; (3) external corrosion of boiler tubes; (4) fractures due to corrosion-fatigue; and (5) corrosion and welding.—R. A. R.

Corrosion of Oil Well Equipment. L. C. Case. (American Society of Mechanical Engineers, Oct., 1947: Petroleum Engineer, 1947, vol. 19, Dec., p. 150: [Abstract] Journal of the Institute of Petroleum, 1948, vol. 34, May, p. 126A). The causes of corrosion of well equipment are reviewed. It is shown that the oil/water ratio and the nature of the oil can be significant factors as well as the nature of the water. The use of resistant materials, alloys, and coating, and chemical methods of combating corrosion are discussed. Fomaldehyde has proved effective in combating sulphide corrosion in many areas, and oil-wetting agents have proved inhibitory. The use of the latter has not, however, been fully investigated at present.

Inhibiting Subsurface Sulphide Corrosion. P. L. Menaul. (World Oil, 1947, vol. 127, Oct., p. 150: [Abstract] Journal of the Institute of Petroleum, 1948, vol. 34, May, p. 126A). The manner in which sulphides cause corrosion and eventual failure of subsurface well equipment is briefly explained. This corrosion can be almost entirely prevented by the daily injection of formaldehyde into the annulus of affected wells. Cases are cited of wells which, after the installation of formaldehyde injection, have been operated at a profit even where sulphide-corrosion damage had previously completely prevented economic operation. The technique employed in formaldehyde injection is briefly discussed and three references are appended.

Corrosion Studies for the Petroleum Refining Industry. Part I. The Economic Aspects of Corrosion. Part II. Factors Affecting Corrosion. Part III. Corrosion Tests. F. A. Rohrman. (Petroleum Refiner, 1947, vol. 26, June, July, Aug.: [Abstract] Corrosion, 1948, vol. 4, June, pp. 34, 36). In Part I the economic aspects of corrosion and basic corrosion theory are discussed. Means of reducing corrosion by routine maintenance, inspection, and replacement have long been the conventional answer to corrosion difficulties, whilst newer effective methods such as the use of more resistant construction materials, water treatment, counter-electrolytic protection, and others have usually been reserved for the difficult cases. Chemical reactions leading to corrosion, including local galvanic action and the action of oxygen, which occur only under ideal conditions are considered in this section. In Part II the following factors affecting corrosion are discussed: (1) Metal (*a*) electromotive position, (*b*) purity, (*c*) nature of impurities, (*d*) physical state, (*e*) oxide or surface behaviour; (2) corroding medium (*a*) salt solubility, (*b*) nature of cation, (*c*) concentration of cation, (*d*) electrical conductivity, (*e*) diffusivity (temperature and viscosity), (*f*) nature of anion, (*g*) nature of corrosion products; (3) external influences (*a*) oxygen concentration, (*b*) light, (*c*) colloids, (*d*) bacteria, (*e*) cathodic metals, (*f*) stray currents. In Part III, six types of accelerated corrosion tests: Electromotive, total immersion, partial immersion, salt and acid spray, wet and dry, and colour tests, are discussed. Corrosion prevention by alloying, removal of strains, polishing, producing insoluble phosphate coatings, electroplating, covering with metals other than by electroplating, covering with non-metallic materials, making cathodic with external electromotive force, and treatment with corroding media are briefly described.

Report on Investigations of the Benzole Technical Committee 1942–1946 on Sludging and Corrosion in Benzole-Absorption Plants. (Ministry of Fuel and Power, 1947: H.M. Stationery Office). This Report by the Benzole Technical Committee, set up by the Ministry of Fuel and Power in 1942, is in three main sections. The first section (A) on sludging is in three parts dealing with: (1) Survey of plant data and tests on oils in use. (2) Laboratory investigation of some factors affecting sludge formation in gas oil. (3) Analysis of sludges from benzole-recovery plants using petroleum oils. The second section (B) deals with investigations of the corrosive action of benzole-absorption oils, and the third section (C) is a discussion of the results of the investigations on sludging and corrosion. Several appendices follow which record: (1) The forms of questionnaire used for obtaining data; (2) tabulated data from coke-oven plants; and (3) methods of test, including: (*a*) Determination of tar fog, (*b*) determination of oxides of nitrogen, (*c*) determination of composition of gas oils, and (*d*) oxidation-sludge test. A list of 94 references is given.—R. A. R.

Sludging and Corrosion in Benzole-Absorption Plants. M. Barash. (Coke and Gas, 1948, vol. 10, May, pp. 176–179). The conclusions in the Report by the Benzole Technical Committee of the Ministry of Fuel and Power (*see* preceding abstract) are discussed.—R. A. R.

Researches on the Corrosion of Metals by Methanol. A. Guillemin. (Annales de Chimie (France) 1944, vol. 19, pp. 145–201: Z.D.A. Abstracts, 1948, vol. 6, Apr., pp. 61–62). This is a very detailed report of work on the corrosion of metals and some alloys by methyl alcohol, both pure and containing certain impurities, such as water, formic acid, and formaldehyde. Six pages are devoted to the corrosion of zinc, which is not attacked by anhydrous methyl alcohol nor by alcohol containing traces of water, though larger amounts do cause attack to begin, but it is soon checked by the formation of a layer of hydroxide. Formaldehyde is without effect, but the presence of formic acid causes corrosion, and several products have been isolated. No hydrogen is liberated in the process, but oxygen is absorbed.

Corrosion Tests in Distillation Equipment. W. Z. Friend and J. F. Mason, jun. (Petroleum Engineer, 1947, vol. 18, May, p. 192 : [Abstract] Corrosion, 1948, vol. 4, June, p. 36). Results obtained from a number of plant corrosion tests in atmospheric crude-oil distillation and in the separation, fractionation, and stabilization of primary products from thermal cracking are presented. Testing techniques are described. Corrosion rates are given in inch penetration per year; the maximum depth of pitting is also reported. Corrosion is discussed with reference to both atmospheric crude-oil distillation and the distillation of products from thermal cracking. In the former, Ni-resist austenitic cast iron alloys (14% nickel and 6% copper, or 20% nickel) are claimed to be more resistant than cast iron under dilute acid conditions. In the latter, 4–6% chromium steels are adequate. Tables are given showing the compositions of metals and alloys used and the results of the tests. The best alloy for each situation is suggested, as follows: (1) The top of crude topping towers (Monel), (2) straight-run gasoline from crude topping towers, and (3) water layer in reflux water separators (Admiralty brass, copper–nickel alloy, or Monel, depending on the acidity), (4) the bottom of crude topping towers (austenitic stainless steels), (5) vapour separator for thermal cracking of gas oil, (6) fractionation of pressure distillate from thermal cracking of gas oil (austenitic stainless steels or 4–6% chromium steels), (7) fractionation of cracked gasoline (Admiralty brass better than alloys of higher copper content under high-temperature conditions), and (8) the bottom of stabilized gasoline re-run tower (Monel).

Algae, Scale and Corrosion Control. F. Lebrecht. (Ice and Refrigeration, vol. 112, No. 1, pp. 35–39: [Abstract] Corrosion, 1948, vol. 4, June, p. 46). A series of tests for the control of corrosion in ammonia condensers was performed, using the following chemicals as inhibitors: Lime, caustic soda, sodium silicate combined with soda ash, sodium silicate, caustic soda and phosphate, and phosphate alone. The specimens were pieces of mild steel about $\frac{1}{2}$ in square and $\frac{1}{4}$ in thick, highly polished on two opposite sides. It was impossible to control *p*H values to the extent that any corrosion protection could be obtained without forming excessive scale. The best treatment was obtained using a form of sodium metaphosphate which shows an average weight loss of 4 mg/500 sq.cm. The results are tabulated.

Test of Nickel Plated A.P.I. Type Joint in Flow Line of Corrosive Distillate Well. B. B. Morton. (Corrosion, 1948, vol. 4, July, Supplement, pp. 1–3). To study the corrosion resistance of nickel-plated tubing, a joint of 2$\frac{1}{2}$-in. tubing was installed in the flow line of the Grey Cox No. 1 well of the Cotton Valley Operators Association, and exposed for nine months. The threading of the coupling and the pipe, as well as the interior of the pipe were nickel-plated with about 6–8 mils. of nickel, but a part of the nickel had been removed from the chamfer of the pipe to offer a location where severe galvanic effects could be expected. Results obtained showed that: (1) The nickel-plating on the threads of the coupling and the pipe and inside the pipe showed no observable corrosion or pitting; and (2) the exposed steel surface showed marked corrosion though not as severe as was expected with galvanic action. The author tends to the opinion that galvanic corrosion did not exist or was quickly eliminated as a major factor in the corrosion of the exposed steel.—R. F. F.

Corrosion in Isomerization of Light Hydrocarbons. N. Fragen, C. W. Nysewander, and W. R. Hertwig. (Industrial and Engineering Chemistry, 1948, vol. 40, June, pp. 1133–1138). The corrosion of a carbon steel reactor, used in the liquid-phase isomerization of light hydrocarbons, by the aluminium-chloride/hydrocarbon-complex catalyst is at the rate of 1–5 in/annum and it may reach 15 in/annum at points of high turbulence. The corrosion rate of the pipelines and vessels handling the reaction products is about one-tenth of that in the reactor. This corrosion has been studied in the laboratory and on the full-scale plant and the most successful means of protecting the steel was the fitting of gunited Lumnite cement liners to the reactors, and to use Hastelloy B for the reactor nozzle, flange, and valves.—R. A. R.

Effects of Hydrogen Generated by Corrosion of Steel. M. H. Bartz and C. E. Rawlins. (Corrosion, 1948, vol. 4, May, pp. 187–206). Large blisters containing hydrogen at pressures up to 2700 lb/sq.in. develop in oil-refinery pressure vessels and gas storage tanks where the contents are 'sour,' *i.e.*, contain hydrogen sulphide, and embrittlement of sucker rods, pump springs, etc., also occurs. These defects are attributed to the production by the acid, of nascent atomic hydrogen which diffuses into the metal until it reaches 'internal rifts,' laminations or slag inclusions, where it changes to the molecular form, incapable of further diffusion, and sets up considerable pressures, eventually causing blisters with associated cracks. A lamellar segregation of phosphorus is blamed in one particular case. Protective coatings of organic or metallic nature seem to be the only cure. In pump equipment, replacement of damaged parts with others either made of non-corrosive material, or coated with Monel metal or aluminium, has proved satisfactory. J. P. S.

Electric Protection of Steel Water Tanks Against Corrosion. R. J. Smith. (Engineering Construction Record, 1947, vol. 60, No. 5, p. 92: Railway Engineering Abstracts, 1948, vol. 3, June, pp. 147–148). Electrical protection against corrosion has been used successfully since 1939 in an elevated steel water tank at Perth, Ontario. It is now known that the use of aluminium and magnesium electrodes reduces the amount of current needed and the stainless steel electrode at Perth is to be replaced by a magnesium rod. Since corrosion does not occur at temperatures of 32° F and below, the electrodes are removed in winter and replaced in spring. When cathodic protection is used the mud which accumulates at first should be removed and the bottom of the tank should be covered with a layer of pure limestone 1-in thick, since calcium carbonate dissolved in the water gives additional protection against corrosion. The *p*H value of the water affects the current density required to prevent corrosion; water from the Great Lakes requires only 0·66 m.amp. per sq.ft., but as much as 4 m.amp./sq.ft. have been found to be necessary for some waters.

Correct Materials Make Feed Pumps Immune to Corrosion-Erosion. H. L. Ross. (Power, 1947, vol. 91, July, pp. 86–88: [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 7, p. 1312). The best feedwater for boilers is the worst for pumps. Six causes of corrosion-erosion in pumps are outlined and methods for eliminating it in carbon steel pumps at present in use, are described.

Boiler Corrosion and Water Treatment. (Admiralty, B.R. 1335, 1945: H.M. Stationery Office). This report provides comprehensive descriptions and theoretical explanations of the various types of corrosion encountered in service according to present knowledge, their frequency and importance, and how they may be avoided or reduced to a minimum. Sections are also given on scale formation, priming, and the chemistry of distilled water, shore waters, and sea water, and on the theoretical basis of chemical treatments of boiler water. Appendices on circulation and heat transfer in boiler tubes, and to explain the terms '*p*H value,' 'ion,' and 'buffer solutions' are provided.—R. A. R.

The Why, How and What of Pipeline Corrosion. M. E. Parker. (World Oil, 1948, vol. 127, No. 13, pp. 184, 186, 188, 190: Chemical Abstracts, 1948, vol. 42, June 10, col. 3719). Causes of the corrosion of pipelines and methods for its prevention are discussed.

Cathodic Processes in Metallic Corrosion. N. D. Tomashov. (Comptes Rendus des Académie des Sciences, U.R.S.S., (Doklady), 1946, vol. 52, No. 8, pp. 691–694: Electrical Engineering Abstracts, 1948, vol. 51, Apr., p. 89). Theoretical curves of cathodic polarization are drawn, showing the relation between the potential of the cathode and the change in the density of the polarizing current for various conditions of operation. These show clearly the regions where the cathodic process is controlled mainly by (1) the rate of the cathodic reaction of oxygen ionization, (2) oxygen depolarization, (3) diffusion of oxygen to the cathode, (4) evolution of hydrogen.

Cathodic Protection of Steel in Hot Water by Alloys of Magnesium, Zinc, and Aluminium. R. R. Rogers and G. E. Viens. (Canadian Mining and Metallurgical Bulletin, 1948, vol. 42, Apr., pp. 216–224). The degree of cathodic protection of steel and the anode corrosion rate were determined when anodes and waters of different compositions were used at temperatures similar to those in domestic hot water tanks. Twenty different anode materials, sixteen of them magnesium–zinc–aluminium alloys were immersed in six different synthetic waters resembling those to be found in various parts of Canada.

The results showed that: (1) Both the degree of cathode protection and the average anode corrosion rate are affected materially by the composition of the anode material and of the water; (2) poor cathode protection is associated with low anode corrosion rate; (3) when the cathode is fully protected the anode corrosion rate may be comparatively low or comparatively high, depending upon the composition of the water; (4) an important relationship exists between the magnesium content of the preferred anode and the composition of the water; (5) the degree of protection is increased as the SO_4 + Cl concentration of the water is increased and thus as its specific resistance is decreased.

Rehabilitation of Pipe Lines in Place, 3″ to 24″, by the Pittsburgh-Eric Process. A. B. Anderson. (Corrosion and Material Protection, 1948, vol. 5, May–June, pp. 6–8). In this process which can deal with lengths of pipe up to 1000 ft, in diameters of 6 in–24 in and more, a mechanical scraper with plough and wire brushes is drawn, or forced by the pressure of the flushing water, through the pipe till all rust, deposits, and remains of earlier coatings are removed. The length is then filled with 'Lectumen,' a bituminous emulsion and a cathode drawn through while current is supplied by a generator; a smooth even coat of bitumen is produced. J. P. S.

The Protection of Underground Pipes against Electrolytic Corrosion. P. Bidart. (Métaux, Corrosion, Usure, 1945, vol. 20, July, pp. 97–98). The author gives an account of a method for the cathodic protection of gas mains and indicates the results of tests carried out after some months in service.—J. C. R.

Zinc Anode Protection Installed during Pipe-Line Construction. O. C. Roddey. (Oil and Gas Journal, 1948, vol. 46, Apr. 22, pp. 87–88).

Cathodic Protection of Steel Surfaces in Contact with Water. P. Sudrabin. (Water and Sewage Works, 1948, vol. 95, Apr., pp. R109–R121).

The Destruction of Material and the Formation of Protective Coatings by Buried Pipelines. L. W. Haase. (Archiv für Metallkunde, 1947, vol. 1, Nov.–Dec., pp. 471–475). The properties of soil which affect the corrosion of pipelines buried in it are discussed. It is of little value to determine the amounts of individual substances in solution in the soil. The important information is whether: (*a*) the soil has a high or low moisture-absorbing capacity; (*b*) it can take up oxygen; (*c*) much water passes through it; and (*d*) the total salt content of the moisture in the soil is high or low. From these data it is possible to determine the protective measures which should be taken.—R. A. R.

Porcelain Enamel *versus* Corrosion. Helen H. Smith. (Corrosion and Material Protection, 1948, vol. 5, May–June, pp. 8–9, 16). Some new applications of porcelain enamel are described, such as self-lubricating bearings for use in corrosive fluids, preheater parts in steam boilers, aircraft engine exhaust systems, light alloy piston heads, and gas-turbine parts. The Porcelain Enamel Institute through the National Bureau of Standards, has developed a series of tests for the corrosion abrasion, impact, and torsion properties of porcelain enamel. J. P. S.

Cathodic Protection of Steel in Sea Water with Magnesium Anodes. R. A. Humble. (Corrosion. 1948, vol. 4, July, pp. 358–370). Results of tests carried out at the corrosion testing station at Kure Beach, N.C., to determine the suitability of magnesium anodes are given. Standard 4-in by 20-in cast anodes of five magnesium alloys were immersed in sea water for three-monthly periods, to study the behaviour of these alloys. Magnesium was found to have a solution potential of −1·5 V. Further tests, using sand-blasted and rusty steel plates, were made. The sand-blasted steel required an excess of 10 m.amp./sq.ft. for initial protection falling to 6 m.amp./sq.ft. Protection of the rusty steel can be achieved with a c.d. as low as 3 m.amp./sq.ft. if a high c.d. was initially applied (50 m.amp./sq.ft.)—R. F. F.

The Culture and Activities of Sulphate Reducing Bacteria. H. J. Bunker and K. R. Butlin. (Proceedings of the Fourth

International Congress for Microbiology, July, 1947, Copenhagen: Bulletin and Foundry Abstracts of the British Cast Iron Research Association, 1948, July, p. 221). Results of an investigation carried out by the Chemical Research Laboratory, Teddington, are presented. Buried ferrous pipes if inadequately protected, are particularly susceptible to anaerobic soil corrosion, caused by sulphate-reducing bacteria with the type name *Vibrio desulphuricans*. The addition of 5% sodium sulphate to an enrichment medium eliminates many infections, but the perfect selective medium has not yet been found.

Salt Water Corrosion of Ships. R. A. Pomfret and L. M. Mosher. (Corrosion, 1948, vol. 4, May, pp. 227–243). The main features of the corrosion of ferrous materials in sea water are well enough understood; the inconsistent behaviour of copper in salt-water piping systems suggests the use of steel or cupro-nickel to give a shorter but more predictable life.—J. P. S.

Marine Lab "Aids" Corrosion Research. E. W. Feller. (Power, 1947, vol. 91, Aug., pp. 90–91: [Abstract] Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Mar., p. 32). A description is given of an experimental station situated by the sea and protected against the force of the waves. Its size is such that 18,000 specimens can be exposed to varying corrosion conditions.

Fretting Corrosion. (Lubrication, 1948, vol. 34, Mar., pp. 25–36: [Abstract] Metals Review, 1948, vol. 21, May, pp. 14, 16). A particular type of corrosion is found on the contact areas of loaded metal surfaces subject to oscillatory or vibrating motion. The phenomenon is also known as 'false brinelling' and as 'friction oxidation.' The nature of the process, the effects of load, surface finish, and materials, and some suggested remedies, including use of lubricants, are discussed.

High-Temperature Oxidation. H. M. McCullough. (Ohio State University, Engineering Experiment Station News, 1947, vol. 19, No. 5, pp. 38–41: Chemical Abstracts, 1948, vol. 42, Apr. 20, col. 2561). The rates of oxidation of types 304 and 410 stainless steels were determined between 850° and 2200° F in nitrogen-oxygen atmospheres containing 2–95% oxygen. The gain in weight of specimens after oxidation and the weight loss after stripping the oxide from the steel were both determined. Both steels can be satisfactorily used in 20% oxygen up to 1600° F. Type 410 steel oxidized more rapidly than type 304. Chromium is the main benefactor in the resistance to high-temperature oxidation of these steels. The following chemical analysis was made of the outside and inside oxide layers respectively, formed on 410 steel at 2100° F in 20% oxygen: metallic Fe 0·26%, 0·38%; FeO —, 6·35%; Fe_2O_3 78·16%, 3·01%; Fe_3O_4 0·93%, —; $FeO.Cr_2O_3$ 19·31%, 91·00%. Analytical data are also given for the oxide formed in 3% and 95% oxygen.

Electropotentials in Growing Halide and Oxide Layers on Metals. A. Dravnieks and H. J. McDonald. (Journal of the Electrochemical Society, 1948, vol. 93, May, pp. 177–190). By the use of an electrode probe, of platinum in the case of air or oxygen, and of spectographic carbon in the case of bromine, iodine, and chlorine, the electropotentials set up across the scales of oxides and halides growing at elevated temperatures have been measured. From these electropotentials the transference numbers have been calculated and found to be in agreement with results from other methods. The oxides on iron, stainless steel, nickel, aluminium, zinc, and molybdenum are found to be electronic conductors; there is doubt in the case of tungsten. Silver chloride and bromide are found to be predominantly cationic conductors, and the lead halides anionic conductors; cuprous iodide exhibits anomalies depending on the temperature and the pressure of iodine, whilst cuprous oxide, though essentially an electronic conductor, posseses a small ionic conductivity.—J. P. S.

Melting Points of Iron Oxide on Silica; Phase Equilibria in the System Fe–Si–O as a Function of Gas Composition and Temperature. L. S. Darken. (Journal of the American Chemical Society, 1948, vol. 70, June, pp. 2046–2053). The migration of silica through iron oxide to the scale-metal interface during the scaling of silicon steels has been studied by means of experiments which determined the melting point of iron oxide in contact with silica (a silica rod was dipped in a suspension of Fe_2O_3 and heated in a tubular furnace) in oxygen, air, CO_2 plus oxygen, and in atmospheres of CO_2 and CO in varying proportions. Fine univariant points were determined for the equilibrium of the phases hematite, magnetite, fayalite ($2FeO.SiO_2$), wüstite ('FeO'), silica, metal, melt, and gas, and fifteen univariant curves connect each three of the above. It is considered that silica, which forms a compound with ferrous but not with ferric oxide, will migrate towards the region where it can form the most stable compound; from free-energy considerations this is seen to be the scale-metal interface.—J. P. S.

The Corrosion of Heat Resisting Alloys Used in the Manufacture of Gas Turbines. P. A. Jacquet and P. Galmiche. (Recherche Aéronautique, 1948, July, pp. 19–26). The corrosion of metals in gas turbines is discussed and the work of various investigators on the oxidation of metals at high temperatures and on the influence of various additions on the behaviour of heat-resisting alloys is reviewed. There are twenty-six references.—R. F. F.

BOOK NOTICES

COTTRELL, A. H. "*Theoretical Structural Metallurgy.*" 8vo, pp. viii + 256. Illustrated. London, 1948; Edward Arnold and Co. (Price 21*s.*).

The theory of metallic structure has developed rapidly in recent years, and a clear exposition of its present position is to be welcomed. Dr. Cottrell approaches the subject from the physical point of view, and is concerned with theory and not with experimental methods which are assumed to be known. Beginning with an account of modern conceptions of the structure of atoms and of the forces concerned in the building up of crystals, the various types of arrangement on lattices are described. Three chapters follow on the application of electron theory to crystals, including wave theory and quanta, Brillouin zones, and applications to the study of cohesion and of magnetic properties. Phase equilibria and polymorphic transformations, diffusion in alloys, order-disorder changes and similar phenomena are discussed in the light of thermodynamics. An interesting chapter deals with diffusion, and here it is clear that the subject has sometimes been oversimplified. Some anomalous results still await explanation. In discussing the equilibrium diagrams of alloys, it is emphasized that, whilst the number and composition of the several phases can be seen from the diagram (determined by thermal analysis and by X-rays), it gives no information as to their arrangement in space, and must, therefore, be supplemented by observations with the microscope. There are also further limitations which are duly noted. The last chapter deals with nucleation and growth.

To the older metallographer the subject seems to have travelled far from the field that could be explored with the aid of the pyrometer and the microscope, but the author's treatment is thoroughly sound, and his book will be found very valuable by those who wish to know the present position of the physical theory of metals and alloys, which touches practice at so many points.—C. H. DESCH.

KIEFFER, R. and W. HOTOP. "*Sintereisen und Sinterstahl.*" 8vo, pp. x + 556. Illustrated. Vienna, 1948: Springer-Verlag. (Price $16.70 paper cover, $17.50 bound).

The authors' earlier book on "Pulvermetallurgie und Sinterwerkstoffe," published in 1943, covered the entire field of powder metallurgy. It is probably not widely known, as only a few copies have reached this country. Whilst a French translation was published last year, it is still not available in English. Suffice it to say that the authors have lifted all material on ferrous powder metallurgy from their earlier standard work and have now prepared this up-to-date and entirely self-contained treatise on sintered iron and steel.

The first part of the book deals with the manufacture and properties of iron powders as well as with the processes which occur in pressing and sintering. The material is very well presented. It is, in fact, interesting to see how fully the work of Leadbeater, Northcott and Hargreaves

(*see* Iron and Steel Institute, Special Report No. 38) and of Alexander Squire (*see* various reports published last year by the Office of Technical Services, Washington) has been incorporated. Adequate space is also allowed for the description of various types of powder-metallurgy equipment, such as presses, sintering furnaces, and atmosphere generators. For the rest, the authors have relied on the classical work done between 1930 and 1940 by Schlecht, Schubardt and Duftschmid, and Sauerwald and Offermann. The discussion generally does not contain any new ideas, but it gives a very clear picture of what can be expected when working with iron powders.

In the second part of the book uses are discussed. It is rightly emphasized that iron and steel made by sintering and by casting are not strictly comparable. Sintered iron and steel is always to some extent porous and, depending on the shape of the compact, possibly of non-uniform density. Measurement of the various physical properties, therefore, requires slightly modified test methods, and the discussion of these is particularly informative. The porosity can be utilized directly as in bearings, or indirectly for packing glands, shell driving bands, revolver bullets, etc. The technical aspects of porous iron bearings are dealt with satisfactorily, but shell driving bands are dismissed rather briefly in two pages, although it is stated that probably 100,000 tons of iron powder were used for this one application during the war. Various sintered machine parts have also been made on a large scale, mainly in the United States. Results obtained by heat-treatment and all the known kinds of surface treatment are fully discussed. A number of other applications are noted, such as sintered iron–nickel–molybdenum and iron–nickel–cobalt for electronic purposes, magnetic dust cores, soft magnetic materials, permanent magnets, iron-bonded diamond tools, and welding rods. Finally, sintered iron alloys are discussed in the order of the Periodic Table.

The book has originated from the fact that the Germans gained a great deal of experience in iron powder metallurgy through making the shell driving band during the war. Certainly, no peace-time development of similar magnitude has been disclosed. The book is very well produced and very informative and it can be safely recommended to anyone considering the practical possibilities of iron powder metallurgy.—W. D. Jones.

"*Pittsburgh International Conference on Surface Reactions*" 4to, pp. 236. Illustrated. Pittsburgh, 1948: Corrosion Publishing Company. (Price $10.00). This volume contains 31 papers representing the present state of research work on surface reactions, presented at the International Conference on Surface Reactions held at Pittsburgh in June, 1948. The Congress was organized by the Electrochemical Society, Pittsburgh Section, in association with the American Chemical Society, Pittsburgh Section, the Electrochemical Society, Corrosion Division, the University Corrosion Conference, the American Society for Metals, Pittsburgh Chapter, the Physical Society of Pittsburgh, and the National Association of Corrosion Engineers. The papers covered the following general subjects: (1) Theory of Liquid Phase Reactions, (2) Theory of Oxidation and Surface Reactions, (3) Preparation of Surfaces, (4) New Methods and Results, (5) Fundamental Mechanisms, and (6) Corrosion and its Measurement. Abstracts of those papers of interest to the ferrous metallurgist will appear in subsequent issues of this Journal.—R. E.

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Kühnl, O. "*Metallfärbung.*" 1 Teil: "*Chemische Färbung.*" 2 Teil: "*Galvanisieren.*" Wien: Verlag Rudolf Bohmann. (Price $8 each).

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